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LECTURES
ON
ASTRONOMICAL THEORIES.

FIRST.—CELESTIAL SPHERE.

SECOND.—PARALLAX AND ABERRATION OF LIGHT.

THIRD.—THEORIES OF LIGHT.

FOURTH.—COMETARY ORBITS.

BY
JOHN HARRIS.

Montreal:
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JULY, 1876.

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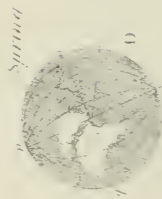
LECTURE FIRST.





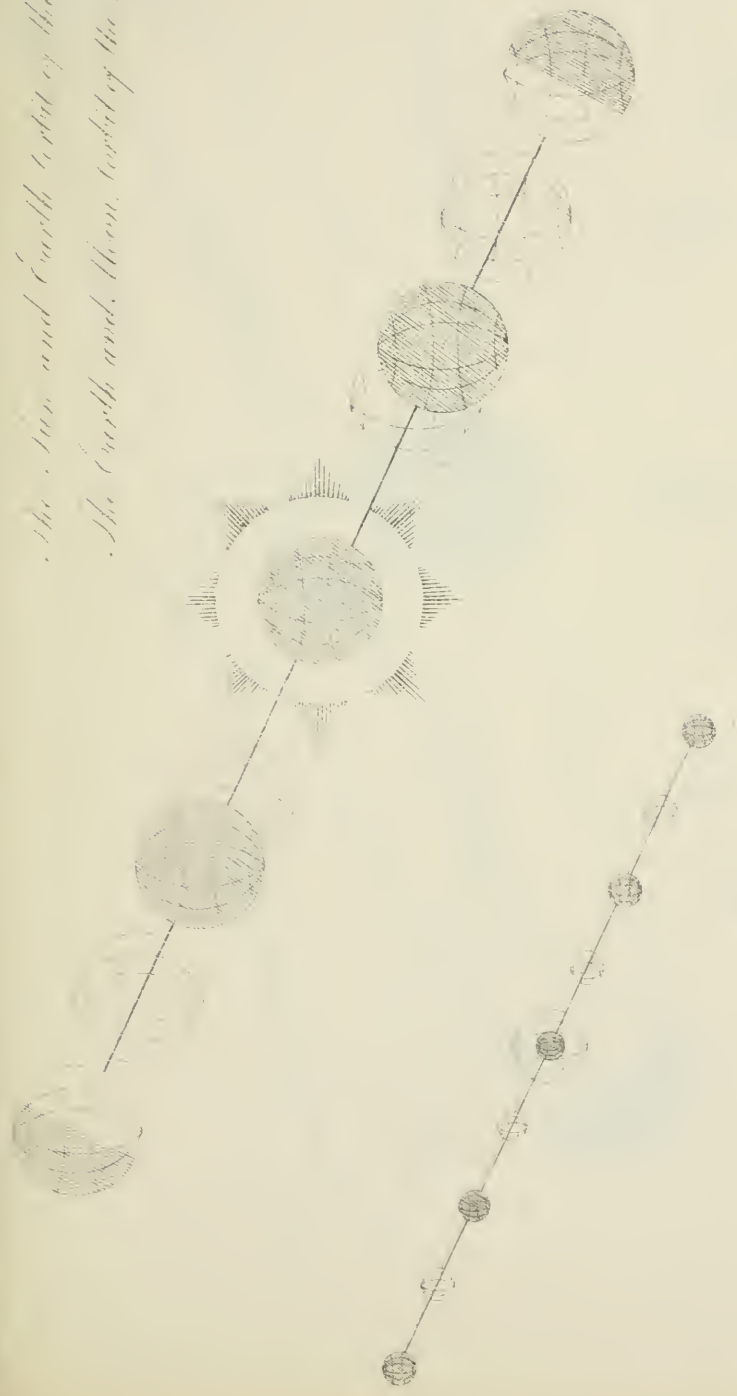
The Sun and Earth

Plat. 8



Illustrating the theory of the ecliptic axis

The Sun and Earth orbit of the earth.
The Earth and Moon orbit of the moon.



Illustrating the theory of the perpendicular axes.

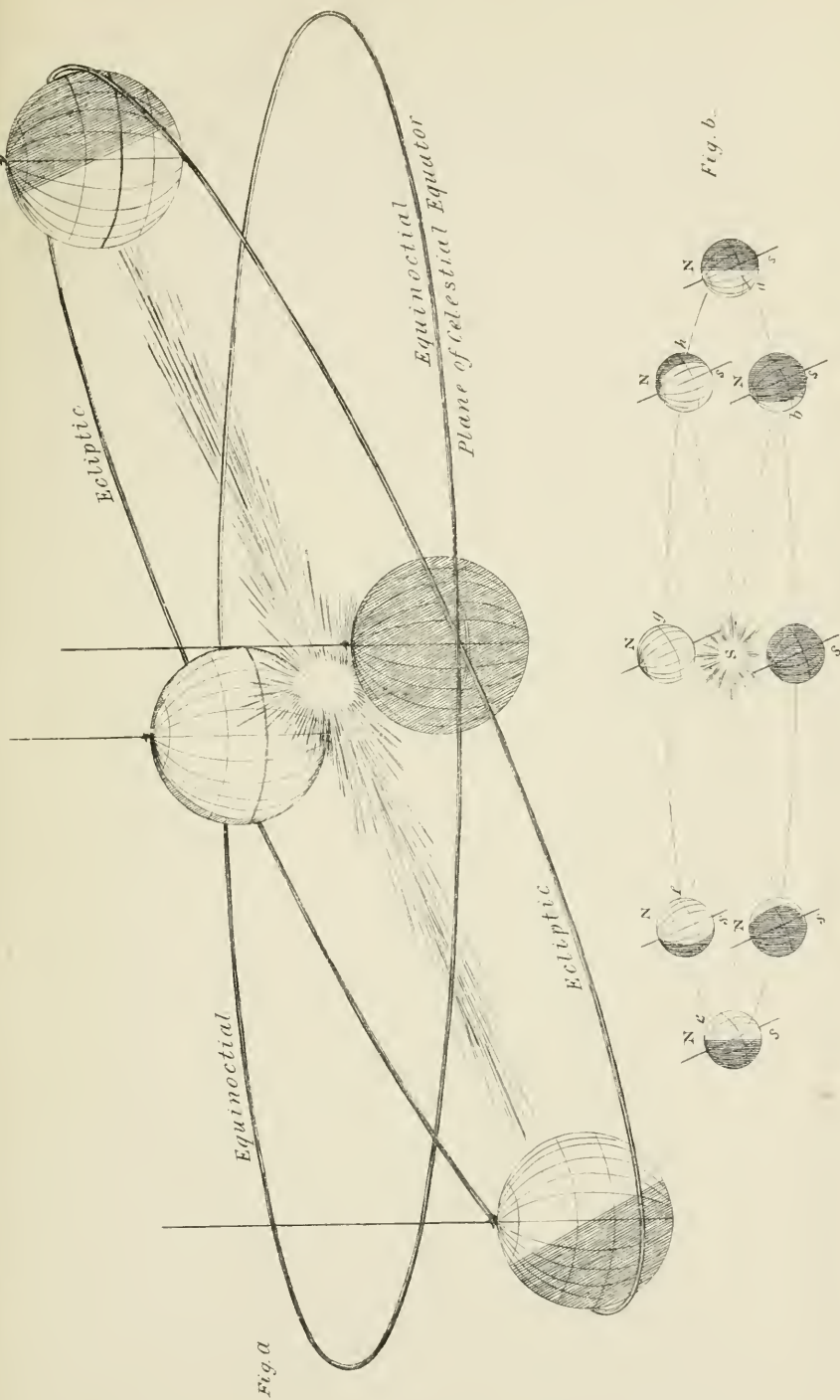


Fig. a Illustrating the theory of the Perpendicular Axis

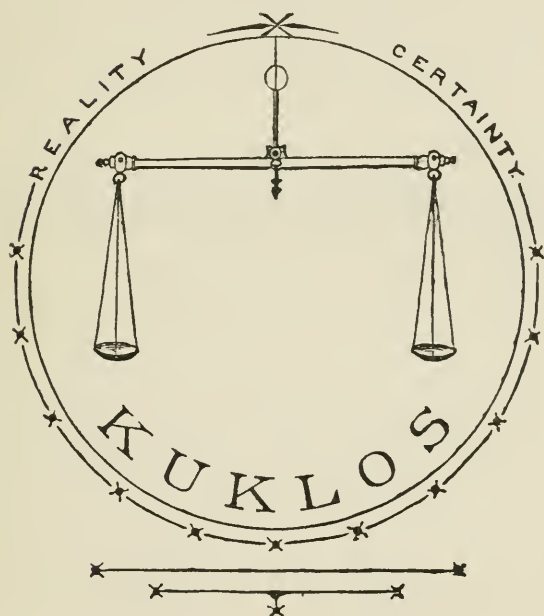
Fig. b Illustrating the theory of the Inclined Axis

THE CELESTIAL SPHERE

AND

THE DOCTRINE OF THE EARTH'S PERPENDICULAR AXIS.

BY
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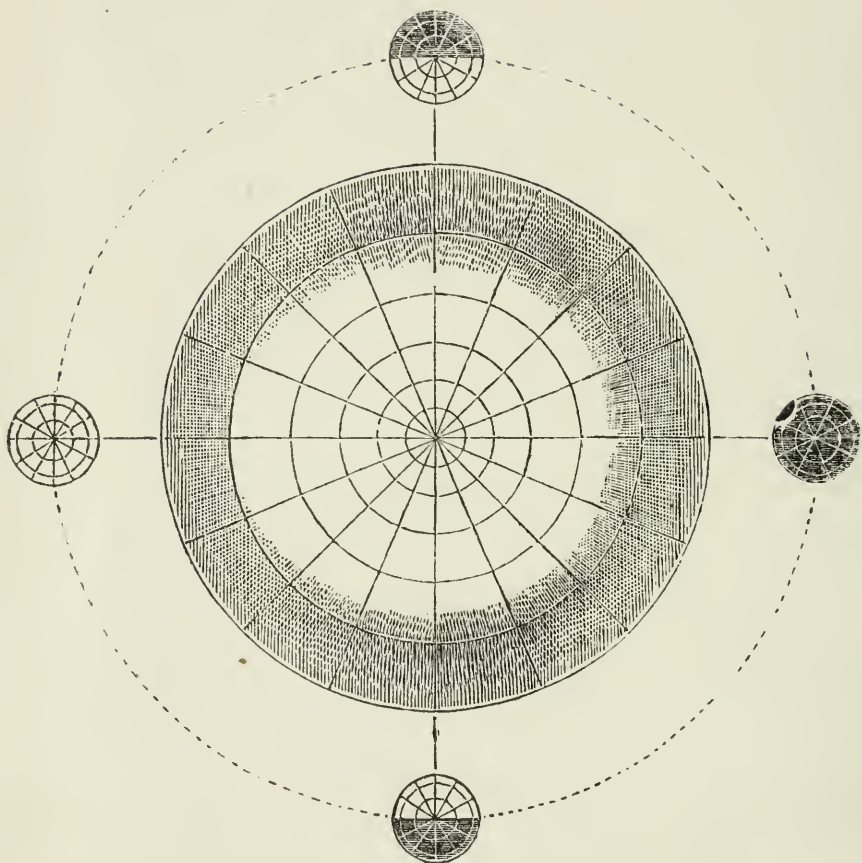
Entered according to Act of Parliament in the year one thousand eight hundred and seventy-six, by JOHN HARRIS, in the office of the Minister of Agriculture and Statistics at Ottawa.

P R E F A C E .

The argument which is the subject of the explanatory lecture about to be put before the reader, has been already published (April, 1875) as the second volume of the series of works on physical science, entitled 'Centrifugal Force and Gravitation.'

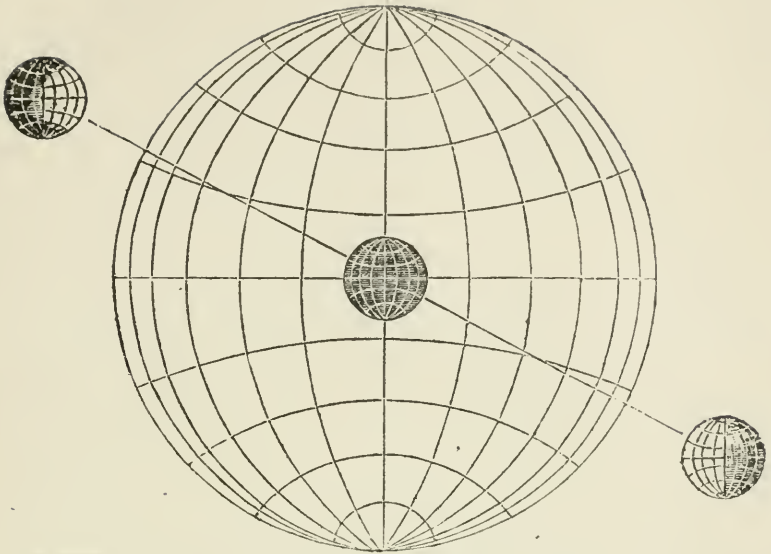
A particular feature of the present exposition is the illustration of the subject by models. The arrangement, however, and, to some extent, the matter, is different to that in the former treatise; to which, indeed, this may be considered introductory. The endeavour is herein made to state the relations of the case as clearly and practically as the orderly method requisite to ensure a correct appreciation of the argument will admit.

Montreal, June 24, 1876.

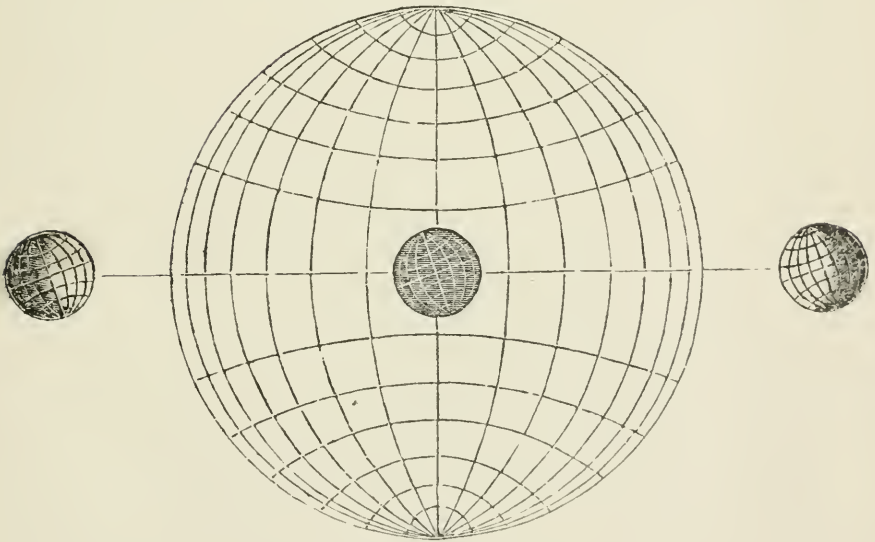


BOTH THEORIES.

VIEW FROM ABOVE.



THEORY OF THE PERPENDICULAR AXIS.

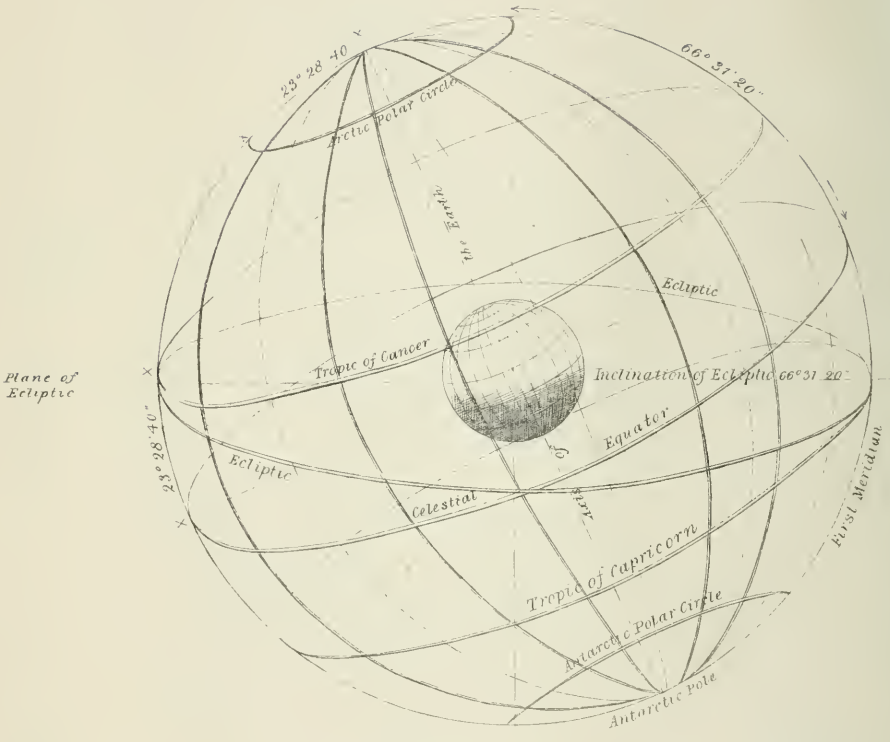


THEORY OF THE INCLINED AXIS.

Plate 3.

Fig. a.

Pole of Ecliptic.

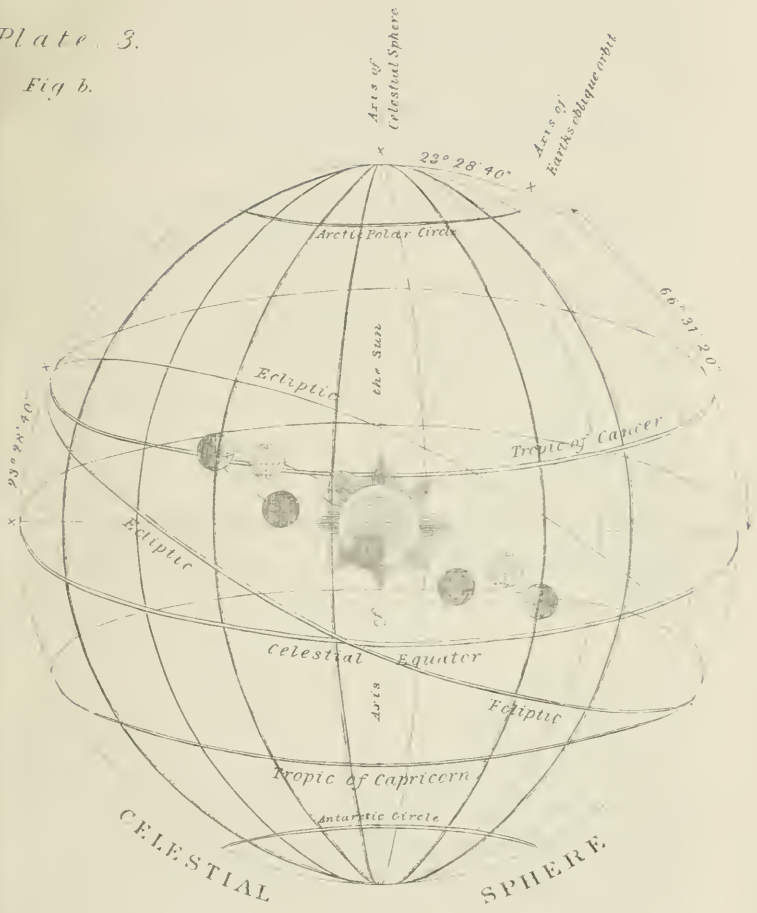


Theory of Inclined Axis.

From A. K. Johnston's
Atlas of Astronomy.

Plate 3.

Fig b.



Theory of Perpendicular Axis.

THE THEORY
OF
THE EARTH'S PERPENDICULAR AXIS.

Is the Earth's position perpendicular or inclined compared with that of the Sun ?

The astronomical importance of this enquiry will be, in some measure at least, apprehended so soon as it is seen that the above question necessarily involves a second question, which is: Does the earth, in its orbital revolution around the sun, travel in an even horizontal path, always in the plane of the sun's equator? Or does it travel in an ascending and descending path oblique to the plane of the sun's equator, and passing through that plane?

Illustration here of the difference in the two orbits attributed to the earth—by means of the models.

Since a just appreciation of the merits of the argument and explanation we are about to offer, is very much dependent upon a correct apprehension of the doctrine of the celestial sphere, it is very important for our purpose of making the explanation intelligible and distinct, that the precise meaning and relations of that expression (the celestial sphere) should from the first be well understood. We will therefore commence with a preliminary explanation of those relations.

THE CELESTIAL SPHERE.

An observer standing on the earth's surface, looks into the clear sky; if it be day time he sees the sun; if it be at night he sees a number of stars. Behind the sun, and behind the stars, he sees (so to express it) an apparent background in every direction in which he looks into the heavens: and, if his station be such that his view of the horizon in all directions is uninterrupted, he sees that this apparent background forms a hemisphere.

We may at once assume that the observer, being ordinarily educated and informed, knows that, if he travelled to the opposite side of the earth, he would see the opposite corresponding hemisphere of the heavens, and he knows, in fact, that the earth on which he stands is a globe or sphere, and perceives that the firmament of the heavens constitutes an apparent sphere of immense size having the terrestrial sphere in its centre. This great sphere, which we will at once call the celestial sphere, contains—the earth, the other solar planets, the sun itself, and the stars. Let us suppose that the observer, being an astronomer, or desirous of becoming so, proceeds to study the alteration which in the course of a certain number of hours, days, weeks, or months, takes place in the apparent situation of the various heavenly bodies, relatively to that of the earth, in the celestial sphere; and endeavours to trace out, from and by means of this apparent alteration, the actual motion of the earth itself (which we will suppose he has already learnt to regard as the actual moving body). Before he can make any progress in such investigation he is brought to a recognition of the *relative* character of

position. The celestial sphere is not a natural reality; it has no actual existence in nature. It is an artificial product of the human imagination, having an express purpose, which purpose is to define the correlations in locality and position of the various stars, stellar systems, and constellations: and to furnish a ready means of distinguishing each from each, of identifying those various bodies, and of detecting any alteration in their relative situations.

Now it is at once evident that the celestial sphere, not being a natural reality, cannot have or be imagined to have an absolute position in space. And, even if it were a natural reality, it could not have or be imagined to have an absolute position in space. In this respect it is in the same case as each one of the spherical bodies which it includes; for neither can any one of them have or be imagined to have of itself an absolute position in space. But in the case of any one of the celestial bodies contained in it, we may do what we may also do in the case of the celestial sphere itself, we may arbitrarily confer upon it a position and locality, and, by doing so in the case of any one of the celestial bodies, we obtain a standard of position and locality which determines relatively the locality and position of all the others. If we suppose the commencement to be made with the celestial sphere itself, and it be determined to call that part, occupied by certain specified constellations, the *east* of the sphere, then a definite localization and position is at once obtained not only for the sphere but for each and all the stars included in it. For that part, distinguished by certain other constellations, opposite the east, must then be the west, and,

from these two points, the north, the south, and all other points of relative locality become determinate. Or, let us suppose the commencement to be made with the globe of the earth. We cannot suppose the earth to have absolute position in space, but it has specific location and position relatively to the other celestial bodies, and, so soon as we arbitrarily confer upon it a definite locality and position by calling one part of its surface the north, or the east, or the west, or the south, we can then determine and define the position of the celestial sphere by calling that part of it immediately over the north of the earth the north of the sphere, that over the east of the earth the east of the sphere, and so on. A person standing on any part of the earth's surface, if uneducated and inconsiderate, might easily suppose himself to be standing on the top of the earth. But another person standing at the antipodes or opposite side of the earth would not readily admit that he was standing head downwards. On the contrary, he might also suppose himself to be standing on the top of the earth. In like manner, persons on those parts intermediate between the other two stations could not be brought to consider themselves standing out horizontally from the earth's surface. Each might claim to be on the top of the earth with as much right as the other. Now since the terrestrial globe is a sphere contained within the celestial sphere, if, having conferred definite position on the celestial sphere, we called that part of the earth immediately beneath the north part of the celestial sphere the south part of the earth, it would evidently be equivalent to asserting that the earth was

posited upside down, or in an inverted position. In the same manner, if the north pole of the earth was made by definition to point to the east or west of the celestial sphere, the position of the earth would be thereby defined as horizontal. If the north pole of the earth is defined as immediately beneath the north pole of the celestial sphere, then the position of the earth is truly perpendicular. And if the north pole of the earth point not exactly to the north pole of the celestial sphere, but a little to the east or to the west of it, then the position of the earth is a little out of the perpendicular, and it is defined as posited obliquely or as inclined at a certain angle. Now, although in the infancy of Astronomy, when the earth was supposed to be the actual centre of the astronomical universe, and the actual centre of what is now known as the Solar system, the ideal celestial sphere with the earth occupying its centre, was quite consistent and in harmony with that supposition, it will become evident, perhaps, on attentive consideration, that, in the present state of Astronomical Science, the location of the earth in the centre of the celestial sphere has become inconsistent and objectionable in a very serious sense. For the fact has been long since established and become recognized as one of the most unquestionable facts of Astronomy, that the earth revolves around the sun, completing one revolution in each year; consequently, if we now suppose the earth to be at all times the centre of the celestial sphere we confer a sort of oscillating eccentric motion on the celestial sphere itself relatively to the sun; because the centre of the

celestial sphere being at a particular time of the year on the one side of the sun, six months later that centre of the sphere will be at the opposite side of the sun. But to admit such a supposition must lead to confusion and misunderstanding ; for the celestial sphere itself is divided, and its parts relatively defined, by means of the fixed stars which apparently are on or near to its surface. Therefore, to admit a supposition that the celestial sphere oscillates or moves relatively to the sun would be to admit that the fixed stars had a corresponding periodical motion relatively to the sun, which would be a supposition quite unsupported by observation and contradicted by the known facts. The supposition of the earth as occupying the centre of the ideal celestial sphere, or, to speak more strictly, the locating of the earth in the centre of the sphere, in the present state of astronomical knowledge, necessitates a continual rectification of the sphere's position relatively to that of the sun. A little further consideration will make evident that the necessity of such a continual rectification must introduce great complexity, abstruseness and difficulty into the consideration of the subject, and, at the same time, if the central location of the earth be adopted and the rectification be neglected, fallacy and error will inevitably result.

My allegation is, or, rather, my argument as opposed to the present doctrine of the earth's position, contains as a part of its allegation, that theoretical astronomy has not recognized the necessity or propriety of making the sun the centre of the celestial sphere ; whereas the prac-

tical astronomer has been, by the logic of obvious fact, obliged to recognize, practically, the sun as the actual centre. Instead, however, of pointing out the impropriety of locating the earth in the centre of the celestial sphere, the practical astronomer has agreed himself to adopt such arrangement, not only in regard to statical astronomy, but also in the department of dynamical astronomy. The result has been the adoption of a compound theory, one part of which is inconsistent with the other, the inconsistency being masked and kept out of view by attaching a sort of double-sense meaning to the terms used to denote certain of the great circles belonging to the celestial sphere* and then using these terms, sometimes in the one signification and sometimes in the other, so as to adjust and re-adjust the theory into apparent harmony with the obvious astronomical facts.

Having made this statement alleging error in the presently adopted theory of astronomy, and having indicated the source and characteristic of the error, the case may now be put on that practical ground, on which it can be rendered intelligible and interesting to those unable or unwilling to deal with the apparent subtleties per-

* The circles here more particularly alluded to are the 'Equinoctial' and the 'Ecliptic.' If the doctrine of the presently adopted theory were sound the 'Equinoctial' would be coincident and identical with 'the circle of the plane of the Earth's equator.' And the Ecliptic would be coincident and identical with 'the circle of the plane of the Sun's Equator.' The astronomer therefore who accepts the theory and, assuming the coincidence, supposes the terms synonymous, uses those expressions sometimes with reference to the circles which they correctly indicate and sometimes in the other signification.

taining to theories of dynamical astronomy. The particular theory, however, to which I am objecting, is in fact supported on that practical ground; for it is argued, by those who uphold it, that the present theory not only satisfactorily explains the known facts and observed phenomena, but that it is the only explanation not obviously unreasonable, which can be given of those facts and phenomena. I shall now proceed to show,—first, that a different explanation satisfactorily accounting for all the known facts and phenomena can be given, and—secondly, that the doctrine now held to explain these phenomena does not in fact harmonize with all of them.

The Theory of the Earth's Perpendicular Axis.

Our celestial sphere has the sun as its centre; and the sun is posited perpendicularly; consequently the polar axis of the sun being extended becomes the polar axis of the celestial sphere. The north pole of the sun is immediately beneath the north pole of the sphere; the south pole of the sun immediately beneath the south pole of the sphere; and so on. Also the equatorial plane of the sun is coincident with the equatorial plane of the celestial sphere. The earth is also by our theory posited perpendicularly—that is, the earth's polar axis is parallel to that of the sun, and perpendicular to the equatorial plane of the sun. It consequently follows that the plane of the earth's equator is (at all times) parallel to the plane of the sun's equator, and that in the earth's orbital revolution around the sun the earth revolves around the polar axis of the celestial sphere (which is identical with the extended polar axis of the sun).

We have now to account by our theory for (1) that group of prominent and familiar facts, collectively known as the phenomena of the seasons; and (2) that group of facts which may be collectively denoted as the apparent path of the sun, viewed from the earth, in traversing annually the zodiacal circle of the stellar universe.

(1) *The Phenomena of the Seasons.*—These are . . . that in the temperate regions, intermediate between the polar circle and the tropics, of the northern hemisphere, the sun shines daily for a time which day by day decreases, during a part of the year, until a minimum is reached; after which, the time, during which the sun is visible each day, commences to increase, and daily increases until a maximum is reached; and then the time again commences, day by day, to decrease. In the corresponding regions of the southern hemisphere, the same variation takes place but in the inverted order, that is, as the daily period of sunshine increases in the northern hemisphere, it decreases in the southern hemisphere; and *vice versa*. Belonging to this reciprocating variation in the daily period of sunlight, in the two hemispheres, is the fact of the semi-annual recurrence of a period called the equinox, during which the days and nights are equal throughout both hemispheres. This period is, as it must manifestly be, intermediate between the maximum and minimum period of the duration of daylight in each hemisphere. The most striking phase, however, of this reciprocating phenomenon, is that which takes place at the regions encircling the

two opposite poles of the earth, namely the regions within the arctic and antarctic circles. It is: that during a part of the year the arctic regions surrounding the north pole, and extending rather more than 23 degrees towards the equator is continually illuminated by the sun, so that during that period there is no night; whilst during the same period the corresponding region in the southern hemisphere, namely, the antarctic, is entirely deprived of the sun's light, and is consequently during that period in continual darkness. To this period succeeds the equinox when the days and nights are equal, and then the conditions of continual daylight and continual darkness in the two hemispheres are reversed, the antarctic regions becoming for a time constantly illuminated and the arctic regions for the same time entirely deprived of light.

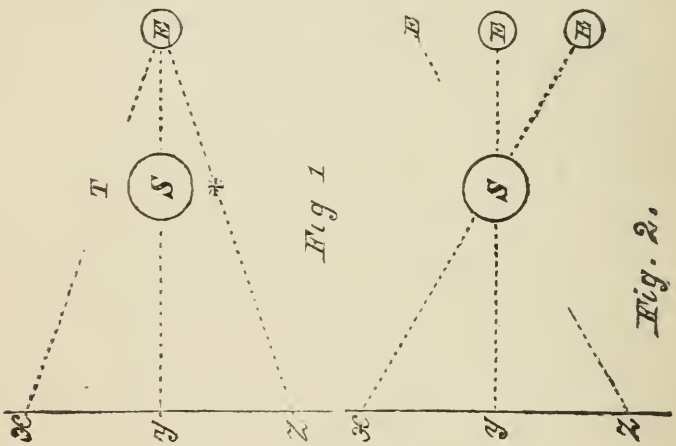
(2) *The Phenomenon of the Sun's annual path in the Heavens.*—This is known to be, so far as the apparent motion of the sun is concerned, a consequent of the actual motion of the earth. But if the celestial sphere be supposed divided into hemispheres by an equatorial circle described on the concave surface of the sphere, and if the sun and the earth be both posited perpendicularly so that the equatorial plane of the earth be coincident with the equatorial plane of the sun, and the equatorial circle of the celestial sphere be also in the extended plane of the sun's equator, then if the earth be supposed to revolve around the sun always in that same horizontal plane (of the sun's equator), it is evident that the apparent path of the sun projected on the concave surface of the celestial sphere would be the same circle—namely,

the circle of the celestial equator. Now in fact the observed phenomenon is . . . that the sun's apparent path is in a circle oblique to the equatorial circle of the celestial sphere, at an angle of about $23\frac{1}{2}$ degrees to that equatorial circle and having its centre coincident with that of the equatorial circle, so that it intersects the latter in two opposite points. The theory of the earth's perpendicular axis is required, therefore, to account for the elevation and depression of the sun's apparent path above and below the equatorial circle of the celestial sphere.

In order to understand the manner in which the phenomenon to which we have referred is accounted for by the doctrine of the earth's perpendicular axis, it is necessary, bearing in mind that the earth and sun are both posited perpendicularly, to consider carefully the orbital path actually traversed by the earth in an annual revolution around the sun. Since if, as the earth proceeds in its orbit, the centre of the earth and of the sun remained in the same horizontal plane, the sun viewed from the earth could not appear to rise above or descend below the equinoctial circle (which is the extension of the sun's equatorial plane to the surface of the sphere), and since in fact the sun does appear to rise above and to descend below that circle, it follows that the earth must actually descend below and rise above the equatorial plane. In Fig. 1.—Let *S*. represent the sun, and *E*. the earth. Let *Y*. be a point in the equinoctial circle* (on the surface of the celestial sphere), and *X*., a point in the ecliptic circle.

*Let *Y*. be one of the two points in the equinoctial in which that circle is cut by the ecliptic.

Since the centres of the sun and earth are both in the equatorial plane, the sun is seen from the earth projected on the sphere in the equinoctial circle at *Y*. Now if the earth continue in the same plane, it will be necessary for the sun actually to rise to *T*. above the plane in order for it to be seen from the earth in the point *X*. of the ecliptic. But by reference to Fig. 2, it becomes apparent that if the earth (*E*.) descend a certain distance below the equatorial plane, the sun, although it remain stationary will appear to the terrestrial observer to have risen above the equatorial plane, and will be seen projected on the celestial sphere at the point *X*. of the ecliptic.



Hence it plainly appears that the earth's orbit is not a horizontal path in the equatorial plane of the sun, but is an ascending and descending path oblique to the solar equatorial plane, cutting through the latter in two places and forming with it an angle of about $23\frac{1}{2}$ degrees. In fact

the circle of the ecliptic, which is the name given to the great circle of the celestial sphere described annually by the apparent path of the sun, bounds the plane of the earth's actual orbit, so that a projection of the earth's path in its annual revolution around the sun, as seen from the sun, on the celestial sphere, is coincident with the ecliptic; only that when the sun, in its apparent path, is at its maximum elevation above the equatorial plane of the celestial sphere, the earth in its actual orbital path is at its maximum depression beneath the equatorial plane of the celestial sphere, and *vice versa*.

The explanation of the phenomena according to the doctrine of the earth's perpendicular axis may be now illustrated by aid of the models:—We will commence by supposing the time of the year to be the vernal equinox in the month of March, when the earth in its orbital path is descending and passing through the equatorial plane of the sun. As the earth continues to proceed onwards from west to east, so does it continue to descend until in the month of June at the (northern) summer solstice it attains its maximum depression; it then, as the onward orbital progress continues, commences to ascend, and continues to ascend. So that in the month of September the autumnal equinox is reached, at which time the earth again passes through the plane of the sun's equator. The ascent of the earth, however, continues, after passing through the plane, until the earth in its orbital revolution arrives in the month of December at the winter solstice, and attains its maximum elevation above the plane of the sun's equator; after which

it immediately recommences to descend and continues to do so, arriving in the month of March at the vernal equinox, and completing an orbital revolution by again passing in its descent through the plane of the sun's equator at the same point from which we commenced to trace its progress. It may be thus seen that the progressive phenomena of the seasons is, by the theory of the perpendicular axis, most readily and satisfactorily accounted for. As the earth continues to descend beneath the plane of the sun's equator, the spherical surface of those parts which constitute the regions of the northern hemisphere are brought more and more into a position to receive vertically the light and heat conferred by the rays of the sun. Whilst to the regions of the southern hemisphere, the progressive descent of the earth so alters its position relatively to the sun that the solar rays reach the surface at that part obliquely and at an angle which increases so long as the descent of the earth continues. And at the extremity of the southern hemisphere, within the antarctic circle, at and near to the south pole, a certain part of the earth's surface becomes (owing to the interposition of another part of the convex surface of the earth itself) unable to receive any of the sun's light, and which part, thus perpetually deprived of light for a season, becomes continually greater as the descent continues until, at the time when the earth attains its maximum depression, this dark region extends to about $23\frac{1}{2}$ degrees latitude towards the equator from the south pole. When the earth ascends, the conditions obtaining in the two hemispheres respectively are reversed: the perpet-

ually dark region surrounding the south pole commences to become, as the ascent of the earth commences, and eventually becomes entirely, the region of perpetual daylight; whilst the region surrounding the north pole, previously the region of perpetual day, becomes conversely more and more deprived of the sun's light until, at the time when the earth reaches its maximum elevation above the sun's equatorial plane (at the winter solstice), the region within the north polar circle, extending from the pole $23\frac{1}{2}$ deg. towards the equator, becomes the region of perpetual darkness. At the same season the temperate zone of the northern hemisphere, intermediate between the arctic and tropical circles, which, at the time of the earth's extreme depression beneath the sun's equatorial plane, received the solar rays vertically or nearly so, now receives them very obliquely, so that the heating influence of the rays is less effective, and the duration of daylight instead of exceeding is now less than the diurnal period of darkness.

The phenomena of the seasons having been thus shown to harmonize with the theory of the earth's perpendicular axis, let us proceed to consider practically and to illustrate, also with reference to that theory, the case of the sun's oblique path as it appears to traverse the heavens in its annual circle around the celestial sphere.

To the astronomer, and to those acquainted with the elements of theoretical astronomy, the explanation may be simplified by stating that the celestial globe as constructed at the present time, correctly represents the celestial sphere in accordance with the theory of the

earth's perpendicular axis, which we are advocating. The equinoctial circle, which is the equator of the celestial globe as now constructed, coincides and is identical with the equator of the celestial sphere according to the doctrine of our theory.* If therefore the sun and earth being both posited perpendicularly in the sphere, and the centre and equator of the earth, being at the season of equinox, in the same plane as the centre and equator of the sun, the earth, always retaining its perpendicularity, proceeded to travel around the sun, neither ascending above nor descending below that plane, the sun's apparent path would obviously be the (so-called) equinoctial circle, and in fact equinox would be perpetual ; but if the earth descend beneath or ascend above the plane of the sun's equator, the angular deviation of the earth must produce to the terrestrial observer an apparent angular deviation of the sun to the same extent, but in the reverse order—thus if the earth be supposed to actually descend one degree beneath the equatorial plane, the sun will appear to rise one degree above the equatorial plane, and so on. Since we cannot mark off the divisions of the celestial sphere by artificial means, the mode has been long since adopted by astronomers of utilizing certain groups of stars, the projection of which upon the celestial sphere serves to indicate the divisions and circles thereof, and

*Assuming that we are correct in this statement, it will at once follow that the celestial globe as now constructed cannot possibly harmonize with the doctrine of the earth's inclined axis. For, according to that doctrine, the earth being posited obliquely, if the equinoctial circle bounds an extension of the equatorial plane of the earth, it (the equinoctial) evidently cannot represent the equator of the celestial sphere.

so denoting those stars, of fixed and determinate locality, that they can be at all times readily identified. Now the equinoctial circle may be roughly indicated by naming the following constellations—the head of *Cetus*; *Orion's belt*; *Monoceros*; *Hydra*; *Virgo*; *Ophiucus*; *Antinous*; *Pisces*. If the earth's orbit were in a plane coincident throughout with the plane of the sun's equator, the apparent path of the sun would be through these constellations. But, by the theory, the earth's orbit deviates from that plane, descending to a maximum of $23\frac{1}{2}$ deg. beneath and ascending to a maximum of $23\frac{1}{2}$ deg. above that plane; consequently the circle described by the sun's apparent path (*i. e.*, the ecliptic) must, conversely, ascend above and descend beneath the equinoctial circle or nodal plane of the sun's equator, to the same angular extent. The circle apparently described by the sun's path should therefore, according to our theory, be oblique to the equinoctial circle and cut through the latter at two opposite points. This agrees perfectly with the observed facts. For the sun, instead of appearing to pass through the constellations we have named above, appears to pass through those known familiarly as the signs of the zodiac, namely, *Aries*; *Taurus*; *Gemini*; *Cancer*; *Leo*; *Virgo*; *Libra*; *Scorpio*; *Sagittarius*; *Capricornus*; *Aquarius*; *Pisces*. These constellations delineate the circle known as the ecliptic which intersects the equinoctial in each of the two opposite constellations—*Pisces* and *Virgo*.

It is therefore shown that the doctrine of the Earth's ascent and descent in its orbital revolution relatively to the equatorial plane of the sun, satisfactorily explains

and harmonizes with the phenomena of the seasons and with the apparent path of the sun in the circle of the ecliptic. We shall hereafter insist more particularly that the obliquity of the ecliptic and the phenomena of the seasons furnish absolute demonstration of the vertical deviation of the earth's orbit from the horizontal plane of the solar equator.

Let us now consider the theory at the present time accepted by astronomers and taught as explanatory of and consistent with the phenomena of the seasons, with the apparent path of the sun, with the reasonable doctrine of the celestial sphere, and with the facts of astronomy generally.

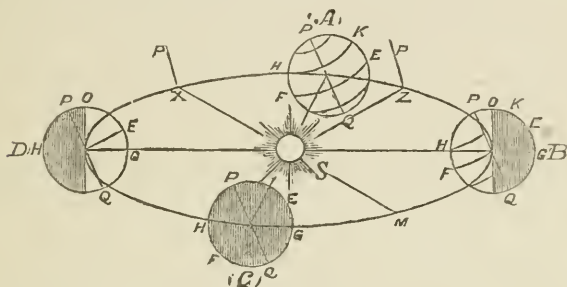
The Theory of the Earth's Inclined Axis.

Sir John Herschel in his "Outlines of Astronomy," in describing and accounting for the phenomena of the seasons, states the theory as follows:—

"In this annual motion of the earth, its axis preserves at all times the same direction as if the orbital movement had no existence; and is carried round parallel to itself, and pointing always to the same vanishing point in the sphere of the fixed stars. This it is which gives rise to the variety of seasons, as we shall now explain. In so doing, we shall neglect (for a reason which will be presently explained) the ellipticity of the orbit, and suppose it a circle, with the sun in the centre and the four quadrants of its orbit to be described in equal times, the motion in a circle being uniform.

"Let, then, *S* represent the sun, and *A, B, C, D*, four positions of the earth in its orbit 90° apart, viz.:—*A* that which it has at the moment when the sun is opposite to the intersection of the plane of the ecliptic *BG*, with that of the equator *FE*; *B* that which it has a quarter of a year subsequently or 90° of longitude in advance of *A*;

“ *C*, 180° , and *D*, 270° , in advance of *A*.* In each of these positions let *PQ* represent the axis of the earth, about which its diurnal rotation is performed without interfering with its annual motion in its orbit. Then, since the sun can only enlighten one half of the surface at once, viz., that turned towards it, the shaded portions of the globe in its several positions will represent the dark, and the bright, the enlightened halves of the earth's surface in these positions. Now, first, in the position *A*, the sun is vertically over the intersection of



the equinoctial *FE*, and the ecliptic *HG*. It is, therefore, in the vernal equinox, and in this position the poles *PQ*, both fall on the extreme confines of the enlightened side. In this position, therefore, it is day over half the northern and half the southern hemisphere at once; and as the earth revolves on its axis, every point of its surface describes half its diurnal course in light and half in darkness; in other words, the duration of day and night is here equal over the whole globe: hence the term *equinox*. The same holds good at the autumnal equinox in the position *C*.

“ *B* is the position of the earth at the time of the *northern summer solstice*. Here the north pole *P*, and a considerable portion of the earth's surface in its neighbourhood, as far as *O*, are situated *within* the enlightened half. As the earth turns on its axis in this position, therefore, the whole of that part remains constantly enlightened; therefore, at this point of its orbit, or at this season of the year, it is continual day at the north pole, and in all that region of the earth which en circles this pole as far as *O*—that is to the distance of $23^\circ 27' 30''$

* “The figure, by a mistake of the engraver, is inserted right and left, so that the earth is made to move the wrong way round the sun, a point of no consequence to the reasoning, and which the reader will rectify in imagination.”

“ from the pole, or within what is called in geography the *arctic circle*. On the other hand, the opposite or south pole *Q*, with all the region comprised within the *antarctic circle*, as far as $23^{\circ} 27' 30''$ from the south pole, are immersed at this season in darkness during the entire diurnal rotation, so that it is here continual night. With regard to that portion of the surface comprehended between the arctic and the antarctic circles, it is no less evident that the nearer any point is to the north pole, the larger will be the portion of its diurnal course comprised within the bright, and the smaller within the dark hemisphere: that is to say, the longer will be its day, and the shorter its night. Every station north of the equator will have a day of more and a night of less than twelve hours' duration, and *vice versâ*. All these phenomena are exactly inverted when the earth comes to the opposite point *D* of its orbit.

“ Now the temperature of any part of the earth's surface depends mainly on its exposure to the sun's rays. Whenever the sun is above the horizon of any place, that place is receiving heat: when below, parting with it, by the process called radiation; and the whole quantities received and parted with in the year (secondary causes apart) must balance each other at every station, or the equilibrium of temperature (that is to say, the constancy which is observed to prevail in the annual averages of temperature as indicated by the thermometer) would not be supported. Whenever, then, the sun remains more than twelve hours above the horizon of any place, and less beneath, the general temperature of that place will be above the average; when the reverse, below. As the earth, then, moves from *A* to *B*, the days growing longer and the nights shorter, in the northern hemisphere, the temperature of every part of that hemisphere increases, and we pass from spring to summer; while, at the same time, the reverse obtains in the southern hemisphere. As the earth passes from *B* to *C*, the days and nights again approach to equality—the excess of temperature in the northern hemisphere above the mean state grows less, as well as its defect in the southern; and at the autumnal equinox *C*, the mean state is once more attained. From thence to *D*, and, finally, round again to *A*, all the same phenomena, it is obvious, must again occur, but reversed,—it being now winter in the northern and summer in the southern hemisphere.

“ All this is consonant to observed fact. The continual day within the polar circles in summer, and night in winter, the general increase of temperature and length of day as the sun approaches the elevated pole, and the reversal of the seasons in the northern and southern hemispheres, are all facts too well known to require further comment.”

Admitting that the theory of the inclined axis, as stated in the foregoing, furnishes an explanation as to the periodical variation in the amount of the sun's light received by the northern and southern regions of the earth at the several seasons of the year; we come now to the enquiry—In what manner is the theory held to account for the oblique circle of the sun's (apparent) annual path in the heavens? Evidently the theory must *seem* to afford to those who hold it some explanation of this prominent and familiar phenomenon. It is manifest that if the centre of the earth be in the plane of the sun's equator, and that as the earth revolves around the sun, its centre continues in the same plane, the sun as seen from the centre of the earth, if referred to that circle in the celestial sphere which bounds the extended plane of the sun's equator, cannot appear to rise above nor to descend below that circle, that is, it cannot appear to deviate from its equatorial plane. The supposition must be, therefore, that the plane bounded by the circle, above and below which the sun appears to rise and fall, is either coincident with or parallel to the plane of the earth's equator, which, by the theory, is oblique to that of the sun. This is in fact the supposition of those who hold the theory at the present time. Let us examine its validity. At the season of winter solstice, the northern extremity of the axis of the

earth, according to the doctrine of the theory, points directly away from the sun at an angle of $23\frac{1}{2}$ degrees.* The astronomer observes the heavens, by day and by night: in the direction of the sun and away from the sun; to the north; to the south; to the east; and to the west. He notes the circle in the celestial sphere which bounds the plane of the earth's equator, and that circle he calls the equinoctial. Where is the place of the sun, at that season, relatively to the so-called equinoctial circle? It is $23\frac{1}{2}$ deg. below the line of that circle.

Let us now accompany the earth to the other side of her orbit. At the expiration of six months, the earth has arrived at the summer solstice. The astronomer again observes the heavens, as before in the various directions—across the sun; away from the sun; to the north, south, east and west; he notes as before, in the celestial sphere, the circle which bounds the extended plane of the earth's equator, and again he calls that circle 'the equinoctial.' Yes! But is that circle which he now, in accordance with the theory of the inclined-axis, calls the equinoctial, the same circle which he, when he observed the heavens from the earth at the opposite side of her orbit, called the equinoctial? No: it is a circle bounding a plane which is parallel to that plane the boundary circle of which he previously called the equinoctial; but neither of these circles can be in any correct sense called the equinoctial, for the plane of the equinoctial must pass through the centre of the sun. Now the plane of the first of the

* As this angular distance has to be frequently repeated, we have, to simplify this explanation, called it $23\frac{1}{2}$ deg. The precise quantity determined by astronomical observation is $23^{\circ} 27' 30''$.

circles, which the astronomical observer called the equinoctial, is situated below the plane of the actual equinoctial, to which it is parallel; and the second of the circles, which he also called the equinoctial, is situated above that plane, to which it is also parallel. Therefore the earth has not travelled in its orbit around the sun in a uniform horizontal plane, as the doctrine of the inclined axis would require us to believe, but has ascended from a lower to a higher plane and then descended from a higher to a lower plane, passing, in its ascent and descent, through the equinoctial plane intermediate between them at the half distance. Now this is precisely what the doctrine of the perpendicular axis states that the earth does. What remains, therefore, to convert the inclined axis theory into that of the perpendicular axis? Simply this: to bring the sun's axis into parallelism with that of the earth and with that of the celestial sphere. For the inclined axis theory, having commenced by positing the earth obliquely, has now posited the celestial sphere itself also obliquely in relation to the sun, and at the same angle as the earth, consequently all that now remains to be done is to bring the sun's axis also into parallelism with that of the earth; perpendicularity will then be restored to the entire solar system, and the oblique characteristic of the earth's orbit (and of the other planetary orbits) compounded of vertical and horizontal motion, will become at once evident.

SUPPLEMENTARY NOTES TO LECTURE FIRST, AND EVIDENCE
IN FAVOUR OF THE PERPENDICULAR-AXIS THEORY.

Solar spots viewed from the earth.

Attentive consideration of the inclined axis and the perpendicular-axis theories, comparing each with the other, can scarcely fail to suggest the probability that careful observations of the solar spots will furnish direct evidence as to which of the two theories is in agreement with the actual facts.

The following quotation from Sir John Herschel's work contains a brief record of the observations which have hitherto been made, accompanied with a statement of the interpretation which is now attached to the observed phenomena.

Herschel's outlines of astronomy. (Page 248 to 251.)

“ 390. When the spots are attentively watched, their situation on the disc of the sun is observed to change. They advance regularly towards its western limb or border where they disappear, and are replaced by others which enter at the eastern limb, and which, pursuing their respective courses, in their turn disappear at the western. The apparent rapidity of this movement is not uniform, as it would be were the spots dark bodies passing, by an independent motion of their own, between the earth and the sun; but is swiftest in the middle of their paths across the disc, and very slow at the borders. This is precisely what would be the case supposing them to appertain to and make part of the visible surface of the sun's globe, and to be carried round by a uniform rotation of that globe on its axis, so that each spot should describe a circle parallel to the sun's equator, rendered elliptic by the effect of perspective.

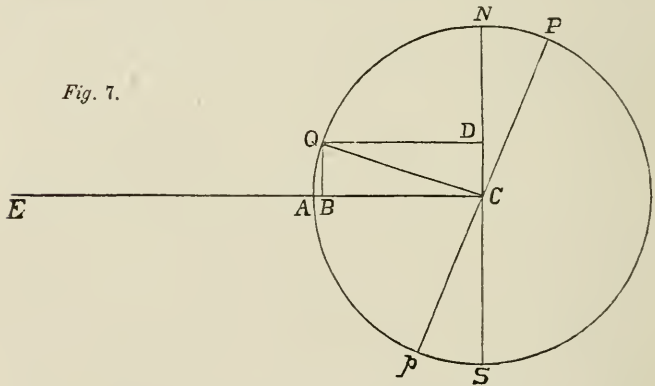
“ Their apparent paths also across the disc conform to this view of their nature, being, generally speaking, ellipses, much elongated, concentric with the sun’s disc, each having one of its chords for its longer axis, and all these axes parallel to each other. At two periods of the year only do these spots appear to describe straight lines, viz., on and near to the 4th of June and 5th of December, on which days, therefore, the plane of the circle, which a spot on the sun’s equator describes (and consequently, the plane of that equator itself), passes through the earth. Hence it is obvious, that the plane of the sun’s equator is inclined to that of the ecliptic, and intersects it in a line which passes through the place of the earth on these days.—The situation of this line, or *the line of the nodes of the sun’s equator* as it is called, is, therefore, defined by the longitudes of the earth as seen from the sun at those epochs, which, according to Mr. Carrington, are respectively $73^{\circ} 40'$ and $253^{\circ} 40'$ ($=73^{\circ} 40' + 180^{\circ}$) for 1850, being of course, diametrically opposite in direction.

“(391) The inclination of the sun’s axis (that of the plane of its equator) to the ecliptic is determined by ascertaining the proportion of the longer and the shorter diameter of the apparent ellipse described by any remarkable, well-defined spot; in order to do which, its apparent place on the sun’s disc must be very precisely ascertained by micrometric measures, repeated from day to day so long as it continues visible, (usually about 12 or 13 days, according to the magnitude of the spots which always vanish by the effect of foreshortening before they attain the actual border of the disc—but the larger spots being traceable closer to the limb than the smaller.) The *reduction* of such observations, or the conclusions from them of the element in question, is complicated with the effect of the earth’s motion in the interval of the observations, and with its situation in the ecliptic, with respect to the line of the nodes.

“ For simplicity, we will suppose the earth situated as it is on the 4th of March, in a line at right angles to that of the nodes, *i.e.*, in the heliocentric longitude $163^{\circ} 40'$, and to remain there stationary during the whole passage of a spot across the disc. In this case the axis of rotation of the sun will be situated in a plane passing through the earth and at right angles to the plane of the ecliptic.

Suppose C. to represent the sun’s centre, *P.C.P.* its axis, *E.P.* the

“ line of sight, $P.N.Q.A.P.S.$, a section of the sun passing through the earth, and Q . a spot situated on its equator, and in that plane, and consequently in the middle of its apparent path across the disc. If the axis of rotation were perpendicular to the ecliptic, as $N.S.$, this spot would be at $A.$, and would be seen projected on $C.$, the centre of the sun. It is actually at $Q.$, projected on $D.$, at an apparent distance $C.D.$ to the north of the centre, which is the apparent smaller semi-axis of the eclipse described by the spot, which being known by micro-metric measurement, the value of $\frac{CD}{CN}$ or the cosine of QCN , the inclination of the sun’s equator becomes known, CN being the apparent semi-diameter of the time. At this epoch, moreover, the northern half of the circle described by the spot is visible (the southern passing behind the body of the sun), and the south pole $P.$ of the sun is within the visible hemisphere. This is the case in the whole interval from December 5th to June 4th, during which the visual ray falls upon the southern side of the sun’s equator.



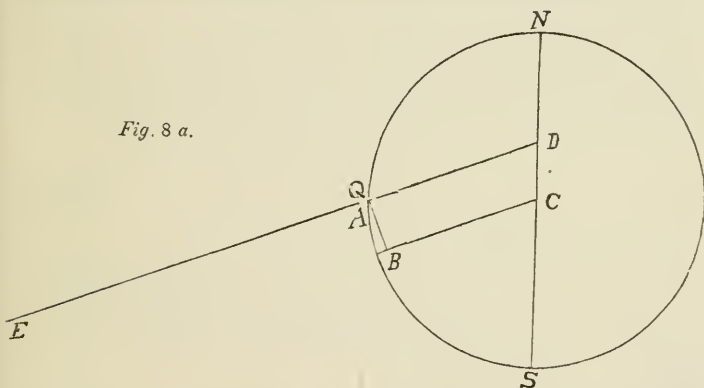
The contrary happens in the other half year, from June 4th to December 5th, and this is what is understood when we say that the *ascending* node of the sun’s equator lies in $73^{\circ} 40'$ longitude—a spot on the equator passing that node being then in the act of ascending from the southern to the northern side of the plane of the ecliptic—such being the conventional language of astronomers in speaking of these matters.

“(392) If the observations are made at other seasons (which how-

ever, are the less favourable for the purpose the more remote they are from the epochs here assigned; when, moreover, as in strictness is necessary, the motion of the earth in the interval of the measures is allowed for (as for a change of the point of sight); the calculations requisite to deduce the situation of the axis in space, and the duration of the revolution around it, become much more intricate, and it would be beyond the scope of this work to enter into them. According to Mr. Carrington's determination, the inclination of the sun's equator to the ecliptic is about $7^{\circ} 15'$ (its nodes being as above stated), and the period of rotation 25 days, 9 hours, 7 minutes; the corresponding synodic period 27 days, 6 hours, 36 minutes.**

The foregoing explanation is evidently based on an assumption that the centres of the earth and the sun are always in the same horizontal plane; or, in other words, that both of them are in the plane of the ecliptic. It is hence concluded that "if the axis of rotation were per-

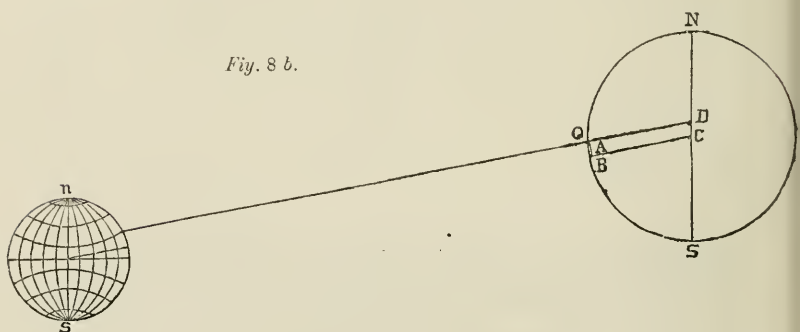
Fig. 8 a.



pendicular to the ecliptic, as $N.S.$ (fig. 7) this spot would be at $A.$, and would be seen projected on $C.$, the centre of the sun. It is actually at $Q.$, projected upon $D.$, &c."

* "These periods are those of a spot in heliographic latitude 15° N. or S. of the sun's equator. Owing to solar atmospheric drift, the periods of rotation deduced from observations of spots in high or low heliographic latitudes differ considerably."

But if we repeat fig. 7, and in fig. 8 (a) we suppose the earth having its polar axis perpendicular to the plane of the ecliptic (which plane is, by the theory of the perpendicular axis, also the plane of the sun's equator, at right angles to the sun's axis of rotation), to have its centre so much below that plane that a line joining its centre to that of the sun will form an angle (of $7^{\circ} 15'$) with that plane—the above statement will obviously no longer hold good; but, on the contrary, the sun's axis of rotation being now perpendicular to the ecliptic, the spot seen at *A*. is also actually at *Q*., (because *A*. and *Q*. now coincide,) and is projected upon *D*., as observed. It is evident that *S*., the south pole of the sun, will now occupy nearly the same position relatively to the place of the earth which was occupied by *P*., the supposed south pole in fig. 7. This is further illustrated in fig. 8 (b), in which the axes of the earth and of the sun are



parallel to each other and perpendicular to the plane of the solar equator; *S*., the south pole of the sun, is within the visible hemisphere, and it now appears that the point

B., mistaken in fig. 7 for the sun's equator, is, in fact, below the equator by the distance *Q.B.**

The distinguishing difference, however, in this connection, between the two theories is that... according to the one, the earth is rapidly and continuously ascending to a higher plane or descending to a lower plane during the twelve or thirteen days the spot remains visible... according to the other, the terrestrial observer watches the phenomena the whole time from the same undeviating plane coincident with the equatorial plane of the sun.*

In § 390, Herschel notes the fact that only on and near the 4th of June and 5th of December, do the spots appear to describe straight lines. Since the inclined-axis theory, and the doctrine of the celestial sphere which belongs to it, furnish no explanation of such a circumstance, it was necessary to seek an independent cause. Hence it was inferred that the sun's axis of rotation must be also inclined, at an angle of more than 7 deg. to the pole of the ecliptic.

The disorderly nature of the arrangement thus suggested, the almost frightful complication (if we may so express it) involved therein, and... hence, the very great improbability which belongs to such an inference, seem

* The difficulty and complexity belonging to the supposition of the inclined terrestrial axis is indicated in the last section (392), of the foregoing quotation in which it is stated that, if applied to (or based upon) observations made at other seasons, and if the earth's motion is allowed for, the calculations become much more intricate.

* This is, however, assuming that he refers his station to the earth's centre; otherwise, by the inclined axis theory, there would be an alteration equivalent to shifting the latitude of his station to the north or to the south on the earth's surface.

to have escaped notice. Whether, in considering the sun's axis of rotation relatively to that of the earth, the obliquity of the sun's position is to be considered an addition to or deduction from that of the earth, is not, so far as we have observed, stated. We will call attention to the circumstance that, in either case, the difficulty of accepting for the earth's orbit a horizontal undeviating plane to which the earth's axis is (considerably) inclined, is yet further augmented by an inference that the sun's axis is also (considerably) inclined to that plane.

Let us now consider the perpendicular-axis theory in its relation to the particular phenomena here noted by Sir John Herschel. The *average* vertical motion of the earth during twelve days is, by that theory, about 3 deg., more when near the nodal plane, less when distant therefrom. Evidently the rapid ascent or descent, relatively to the sun, of the terrestrial observer's station, must considerably affect the apparent motion of the horizontally moving solar spots which he is watching during the successive 12 days. There are only two brief periods, during the annual revolution of the earth at (either of) which a temporary cessation of the earth's vertical motion will allow him to observe the spots move straight across the sun's disk . . . horizontally or nearly so. Those two periods are (about) the beginning of June and the middle of December . . . namely, at those times when the earth, having completed its descent or ascent, moves horizontally in its orbital path for a short time before recommencing its vertical motion in the opposite direction.

THE SOLAR-SYSTEM, AND THE PHYSICAL ARRANGEMENTS OF THE STELLAR UNIVERSE.

A case which belongs as a corollary to 'the theory of the ellipticity of the planetary orbit' appears to us to have been hitherto, at least in a great measure, overlooked, and to constitute a difficulty of which the present doctrine of orbital revolution renders no satisfactory solution.

The case may be thus stated :—The earth's orbit, for example, is an ellipse. Now when, in connection with the present doctrine, we attentively consider this statement of a circumstance, the evident meaning thereof is—that the earth's orbit, which would otherwise be a circle, posited horizontally, makes one great oscillation, receding away from, returning, and again advancing toward the sun, during a revolution ; or, to speak more precisely, the earth being at the average distance of its orbit from the sun, recedes through a certain space to a further distance, whilst revolving around the sun, then returns again to the average distance of its orbit, and approaches nearer to the sun by a space equal to that by which it previously receded, then again returns outwards to the average distance of its orbit and performs the whole of the operation exactly in the time occupied in completing one revolution around the sun. It is in the last stated part of the case we find the difficulty alluded to. .Why should the time of such an oscillation coincide with the time of the orbital revolution ? Or, to put the question more strongly. .How is it possible the times of the two performances can continuously coincide

if the circumstances be such only as supposed by the ordinary doctrine? The two motions differ in character, for the one is a reciprocating or oscillating motion and the other is continuously progressive in the same uniform direction,—namely, at right angles to the radius of the circle in which it revolves. The only interdependence or co-relation of the motions is that arising from the relation of the law of equable areas to the law of gravitation, which has been fully explained in Part First.* But this, of itself, is insufficient, for if the magnitude of the oscillation be augmented and the average velocity of motion in the orbital revolution remain unaltered, the coincidence in the times of the oscillation and of the revolution will be disturbed and destroyed. No direct interdependence has been shown such that the one motion can be considered to restrain, control, and regulate the other, nor does any application of gravitative or other force suggest itself which could fulfil the conditions required by the present doctrine, namely, whilst restraining the revolving body from any deviation whatever above or below the orbital plane, to so control and regulate the reciprocating centrifugal and centripetal motion as to insure the continued and permanent isochronism between the complete oscillation and the complete revolution in the same plane

(b.) *The Precession of the Equinoxes.*

Closely connected with the circumstances belonging to this case, is that phenomenon called the precession of

* Part First of the series entitled 'Centrifugal Force and Gravitation.'

the equinoxes. Now if the precession of the equinoxes were merely a retrogression of the equinoxes it might be reconciled with the present doctrine of the inclined axis, and admit of ready explanation by supposing the time of the complete orbital revolution to gain very slightly upon the time of the complete oscillation; but the so-called precession of the equinoxes includes also a corresponding and equal retrogression of the earth's aphelion and perihelion and of the solstices. Now the solstices are by the theory of the inclined axis dependent upon the inclination of the earth's axis in space relatively to the pole of the ecliptic or to the axis of the sun considered as the standard of perpendicularity. There is, therefore, no reason shown why a progression or retrogression, in the orbit, of the earth's aphelion and perihelion (or of the equinoxes) should be accompanied by a similar change in the time of the solstices. On the contrary, the fact that the alteration in the time of the one is accompanied by a corresponding and equal alteration in the time of the other goes far to demonstrate that the inclined axis theory does not furnish a true and sound explanation of the facts in this connexion. The difficulty has not been overlooked by the theoretical astronomer, but to account for it a most intricate and singular hypothesis has been imagined (devised) according to which the earth's axis and also the pole of the equinoctial, travel around the pole of the ecliptic in a sort of independent supplementary orbit (of 47° diameter) with such a velocity as to require nearly 26,000 years to complete a single revolution, and which has no other apparent object than to produce and ac-

c

count for the precession of the equinoxes. The hypothesis seems, indeed, to be purely imaginary (notional) and unsupported; it is in a high degree objectionable because it infers a want of perfection, simplicity, and order in the work of the Creator, and is quite obnoxious to the general harmony characteristic of the dynamical arrangements pertaining to the stellar universe. *

Having briefly indicated these additional objections to the inclined axis theory, we will now revert to . . .

The theory of the perpendicular axis.

With aid of the explanations already given a little consideration will make apparent that by this theory the phenomenon called precession of the equinoxes is satisfactorily accounted for as a very slow retrogression of the vertical oscillation; in other words, the orbital revolution gains in time very slowly but continuously on the vertical oscillation, and completes the circle of its orbit sooner by a very minute portion of time than perfect isochronism with the vertical oscillation would admit of. *

* The indescribably complicated effect, compared by Sir John Herschel to "a pegtop or tee-totum when it spins not quite upright," is applied directly to the axis of the earth, which carries with it first the equinoctial circle, and then, if we apprehend aright, the whole celestial sphere, with exception of the pole of the ecliptic around which this gyratory effect takes place.

* If the assumption of a central sun, around which our solar system revolves in an orbit of vast extent, be tentatively accepted as scientifically reasonable . . . We then have a probable and sufficient cause to which the precession of the equinoxes may be attributed as a consequent; for the effect thereby produced would evidently be precisely of that character manifested in the precession of the equinoxes . . . to wit, a very gradual and constant gain in time by the complete revolution compared with the oscillation.

Plates 1, 3, & 5 ; Fig. 3 ; and, also, the figure, *page 78*, may be referred to in illustration of these and of the preceding remarks.

(c.) Relation of the Vertical Motion to the Compound Oblique Orbit.

We have not as yet stated or proposed any general law prescribing and limiting the quantity of that vertical motion which forms a part of the compound oblique orbit of each planet. The earth, by the theory of the perpendicular axis, ascends through $23\frac{1}{2}$ deg. above the nodal plane, and descends $23\frac{1}{2}$ deg. below that plane, together 47 deg. of vertical motion. The question is. . . whether, in the case of planets at a greater or lesser distance from the sun than the earth, the vertical motion is proportional, directly or otherwise, to the distance.

In the absence of any astronomical investigation, that is, of subjective astronomical observation, we opine that the vertical motion in the case of each planet will be found to be simply proportional to the distance of the planet from the sun : for, if the distance of the planet (the earth for example) from the sun be supposed doubled, the same decrease in the intensity of the solar attractive force which had for its consequent in the one case an increase in the magnitude of the orbit and decrease in the orbital angular velocity, will have for its consequent in the other, a proportional increase in the longitudinal magnitude of the arc of vertical motion and a decrease in the angular velocity of that motion likewise proportional.

To state that the amount of the angular vertical motion in the case of each planet is directly proportional to

the distance of the planet from the sun, includes the statement, however, that the angular motion of all the planets belonging to the system is the same, or in other words, that, in the plan of the solar system, there has been allotted an equal amount of angular vertical motion to each planet, so that the angle of extreme elevation and of extreme depression is the same for all.

If it be found that this proposition is supported by astronomical fact, it will immediately appear that the relation of this particular angle is of great general interest because of its selection as a part of the fundamental scale on which the dynamical arrangements of the solar system have been made. Can the astronomer declare with certainty the cyclometrical value of that angle? The reply if made hastily would be,—Yes, the angle must be 47° , because such is the vertical motion of the earth ascertained by observation; and, by the proposition, the angle is the same for all the planets.

But on considering the relation attentively, it appears that this angle is, in respect to a small part of it, dependent upon the absolute fixity, on the one hand, or the parallactic displacement, on the other, of the so-called fixed stars which together constitute the standard of reference whereby the apparent obliquity of the ecliptic is determined. This question we have already considered (lecture second) and concluded that the stars must be subject to a parallactic displacement of a very notable amount and which, in those stars principally referred to as standards of locality, may probably amount to nearly two degrees of total displacement.

By assuming hypothetically that such an amount of parallactic displacement in the stars is occasioned by the movement of the earth from the one side of its orbit to the opposite, the vertical angle of orbital obliquity for the earth, and therefore, in the preceding assumption, for all the solar planets, becomes 45° , instead of nearly 47° .

To support this view as a theory, we have.....

(1) The necessity of admitting that a considerable parallactic displacement of the stars must actually take place ;

(2.) The probability that, from the manifest and manifold advantages in such a combination of a simple definite relation between the horizontal and vertical motions, the one would be made an aliquot and prime divisional part of the other, such as the one-fourth.*

Vibration of the Earth's Axis. (Libration of the Earth.)

We have hitherto, in stating the doctrine of the perpendicular axis, considered the earth's polar axis to preserve perfect perpendicularity throughout the ascent and descent of the earth in its orbital revolution. There are, however, reasons, based on careful astronomical observation, for attributing a certain small arc of vibration to the earth's polar axis.

If the supposition of such a vibration (libration) be entertained assumptively, and confirmed by subjective observation, there can be no reasonable doubt as to its

* That is, double the octant of 45° . Because the complete oscillation belonging to one complete orbital revolution includes one ascent and one descent, each of them throughout the extent of the vertical motion; and, therefore, the complete vertical oscillation equals the quadrant of 90° .

particular character,—namely, that as the earth ascends above the nodal plane (at which plane its position would be strictly perpendicular) the south pole and regions of the southern hemisphere, on which the sun's gravitation would act more powerfully than on the northern part of the earth, would (relatively) approach the sun, whilst the north pole, being relatively less attracted, would recede in the same ratio from the sun. When the earth, having on its return downward recovered its perfect perpendicularity at the nodal plane, descends below that plane, the conditions are reversed; the north pole and northern regions will be attracted towards the sun, and the south polar regions recede in an equal ratio.

What reasonable ground have we for tentatively accepting such assumption?

(1.) That such a vibration of the earth is probable and natural; from the known relation of force and motion there must be a tendency to such vibration, and, unless entirely counteracted by the effect of the earth's rotation on its axis the tendency must result in an appreciable effect.

(2.) The careful astronomical observations made by Dr. Bradley, from the year 1725 to 1727, and which led to his adoption and proposition of the theory of aberration. We think that the results of those observations afford strong evidence in favour of, and may go far towards demonstrating, a libration of the earth such as supposed above.

Fig. 9 is a sectional illustration of the earth's (or other planet's) vertical motion thus modified.

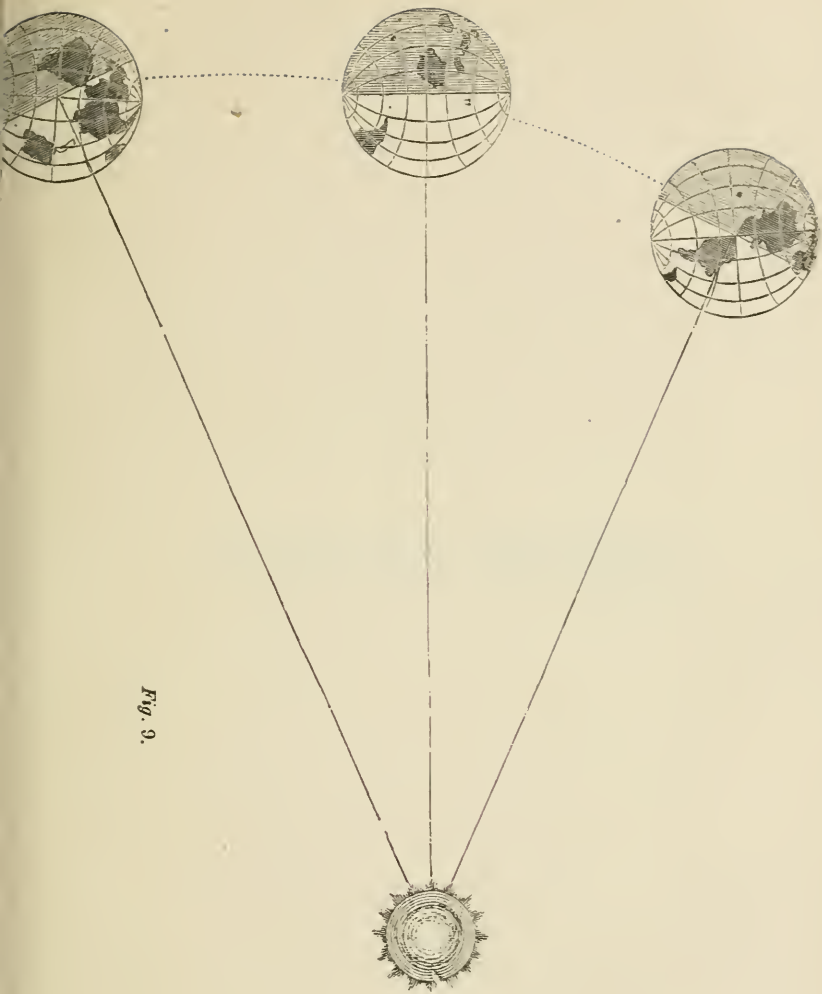


Fig. 9.

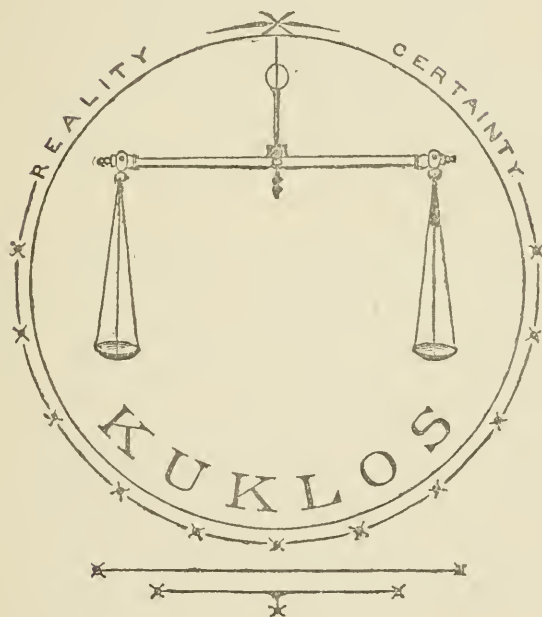
LECTURE SECOND.

PARALLAX

AND

ABERRATION OF LIGHT.

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LECTURE SECOND.

PARALLAX AND ABERRATION OF LIGHT.

The division of the subject to which I am about to direct your attention this evening, may appear to those who have not already paid particular attention to it, very different in character from that which we considered the other evening. So different, indeed, it may at first appear, as to suggest, perhaps, the enquiry whether we are not entering upon a really different subject.

Before re-commencing I am desirous to add a few words to the introductory remarks, which preceded the former lecture, in order to prevent the purpose of these explanatory lectures from being in any degree misunderstood. I wish to remind you that their purpose is to furnish such explanation and instruction on the general subject, to those who are, or who wish to become, interested in it, as may enable them to form their own opinion and exercise their own judgment in regard to certain doctrines now taught as belonging to and forming part of astronomical science.

However interesting the study itself may be, and however advantageous, as a source of gratification and pleasure to the individual, a full general acquaintance

with such a department of knowledge as astronomy may be, it is by no means necessary that persons not possessing such full general knowledge thereof should be debarred from taking part in the consideration of *particular* questions belonging to it. We are, all of us, *reasonable* beings; and, as such, a right or wrong conclusion on a question of educational importance, whatever particular department of knowledge it may belong to, should be of interest to each one of us. Now the questions I am bringing under your consideration, connected, as they will be found to be, one with the other, are, nevertheless, distinct questions, each in itself of great interest and importance; and, in regard to which a general knowledge of the science it belongs to is by no means essential to enable a person to take part in the consideration thereof and to assist the public with his individual share of reasoning power as one of the public, in coming to a sound conclusion about it. There are questions, certainly, the useful consideration of which require special knowledge, attainable only by special education, upon which it would be simply foolish to ask persons, not possessed of such knowledge, to reason. But these are not such questions.

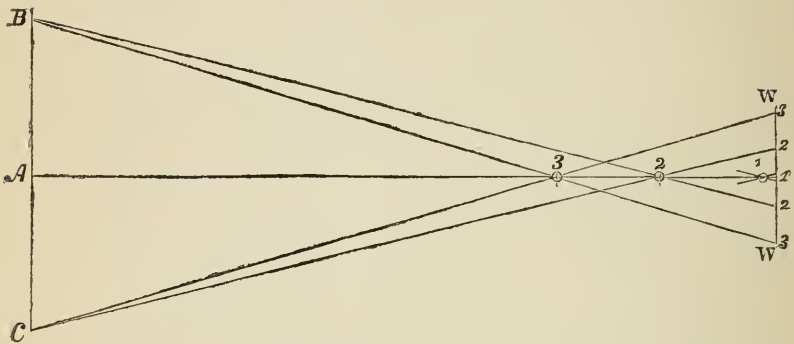
I may be told the general public will not interest itself in questions belonging to physical science or in educational questions of a high character; but *that* I believe to be dependant, at least in some measure, upon the manner in which such questions are submitted to the public. Almost any one only slightly informed on the relations of a subject, and unacquainted with the scientific

nomenclature belonging to it, may be readily driven away from the consideration thereof by treating the subject in what may be called the abstruse scientific manner, with such profuse use of unexplained terms and expressions as can scarcely fail to hurt the feelings of those who do not understand them, and which are naturally resented by them as a sort of scientific jargon. Of parallax, for example—some one might say: Here is a subject I know nothing whatever about. It is quite useless for me to reason about parallax because I don't know what it means, never having paid any attention to it. Now there are questions belonging to parallax to the determination or consideration of which a knowledge of mathematics is essential, and to acquire even a moderate general knowledge of the subject of parallax, attentive study carried on for a few weeks at least would be requisite, but, nevertheless, a correct knowledge of what parallax is, of its characteristics, and of its relations sufficiently to reason advantageously on some questions of importance belonging to it, may be acquired, by any person of moderate intelligence, ordinarily educated, in a very short time.

Parallax may be defined as—the alteration in the apparent locality of an object caused by the actual alteration in the point of view of an observer. Or, in other words, *parallax* is the alteration in the visual angle at which an object is seen in consequence of movement by the observer from one place to another place. Let three objects marked 1, 2, 3 respectively be in a line from the place A. of an observer and at such different distances from the flat surface of the wall *W. W.*, that the object

numbered 1, is almost close to the wall ; No. 2, is considerably further from the wall than No. 1 ; and No. 3, is yet further from the wall than No. 2. Now if the observer move from his station at A. to a station at B, considerably to the left of A., the effect will be that a line from his eye through the object No. 2, if continued to the wall, will strike the wall at the place marked No. 2 thereon ; and a line from his eye through the object No. 3,

Fig. 1.



will strike the wall at the place, marked No. 3, still further to the right : whilst a line from his eye to the first object which is almost close to the wall, will strike the wall only a very short distance to the right. Now if the observer return past his first central station at A., and move to C., a place as far distant to the right of A. as B. was to the left of A., then, lines, drawn from his eye through the objects 2 and 3 respectively, will strike the wall to the left of the central line as shown in the figure. . the entire distance to which each object suffers such apparent displacement being proportional to the distance of the observer's station from the central station, and to the distance of the object from the wall. This apparent

angular displacement of the object in consequence of alteration in the observer's station, is called parallax of the object.

Fig. 2.—Let $A.B.$ represent the diameter of the earth's orbit; and $m.$ and $n.$ two stars at different distances. As the earth removes from $B.$ to $A.$ the nearest star undergoes angular displacement from $m.B.$ to $m.A.$ in the celestial sphere. And $n.$, the more distant star, a similar displacement from $n.B.$ to $n.A.$

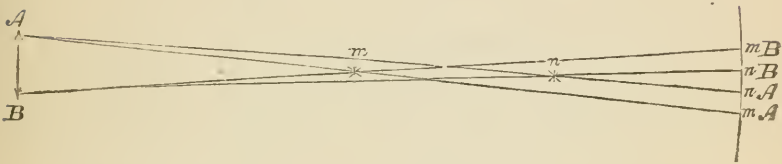
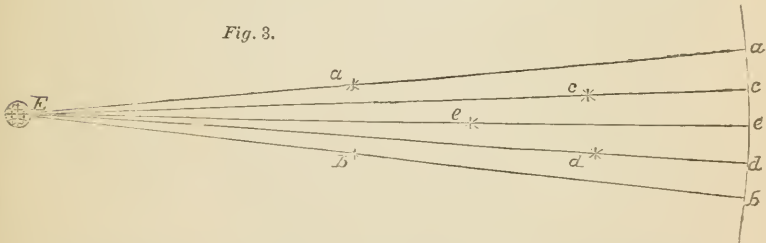
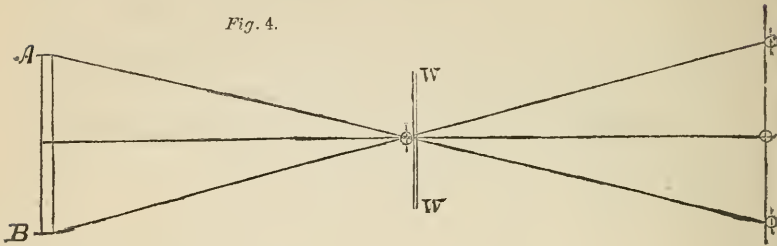
Fig. 2.

Fig. 3.—Let $E.$ be the earth; and $a.$ and $b.$ two stars, at a certain distance from each other and a certain distance from the earth; and let $c.$ and $d.$ be two other stars the same distance apart as $a.$ and $b.$, but twice the distance

Fig. 3.

from the earth; and let $e.$ represent a fifth star intermediate in situation between the others as shown in the figure. Viewed from the earth, the five stars may present the appearance of an equidistant series. . . one under the other, with equal intervals.

Now if the reader apprehends the general principle of Parallax, he will be able to consider with me a case which has been hitherto, I believe, somewhat overlooked, even in advanced treatises on theoretical astronomy. Let



$A.B.$ be a space on a road, say 100 feet in length, and let $d.$ be a tree at a hundred yards distance, close against a high wall $W.W.$ If an observer walk from $A.$ to $B.$, looking at the tree against the wall; the tree will not furnish any parallax. . . , and if there be any mark behind or above the tree by which to identify its place on the wall, that place will be seen to remain the same whether the observer be at $A.$ or at $B.$, or any where between them. But, now, take away the wall, and refer the first tree to a second tree behind it, at a distance of 200 yards from the road; let the observer again walk the distance $A.B.$ observing the first tree with reference to the second, and it (the first tree) will be found to furnish a very considerable and notable amount of parallax.

If we now, bearing this case in mind, contemplate the celestial sphere, we feel the necessity of considering the nature of that which we are accustomed to call the concave surface of the heavens, or of the celestial sphere. There is no material screen close behind any of the stars.

Concave limit of
vision.

Distant Star.

Earth's Orbit.

It is the boundary distance of human vision which presents itself to us as the background upon which the stars are projected: and that background is necessarily more distant than any of the visible stars. When we find a statement that the apparent angular size of an object decreases as the distance increases, we can readily agree that such must be the case. If we find a statement that, supposing the entire solar system to be visible from a distant star, it would occupy but a very small apparent space in the heavens, we should be inclined to ask what definite value is to be attached to the expression 'very small space.' But if told that we can readily conceive the earth's orbit to become a mere point in space, if viewed from one of the most distant visible stars, we should demur and object that, as the earth's orbit is in angular magnitude about 230 times the size of the sun, it is probably at least 100 times larger than the largest star. Now it is quite possible that the earth may not, from want of illumination, be actually visible from a star comparatively very near to the solar system; but, if it be supposed visible from the most distant visible star, its orbit must certainly, as viewed from the star, have a very sensible and notable angular magnitude. And if we

suppose the earth to be seen in duplicate at the opposite sides of its orbit at the same time, it would, we should say, necessarily be cognizable from the star as two distinct points having a notable quantity of space between them.

Now if I may assume that the explanation of the meaning of parallax has been sufficiently explicit to enable you to clearly apprehend its essential characteristics, you will not have, I think, any difficulty in agreeing with me, that the phenomenon of the sun's annual path in the heavens, or, more strictly speaking, over the concave surface of the celestial sphere, is an example of parallax. As the earth actually changes its place by travelling onward in its orbital revolution, the sun, to the terrestrial observer, appears to move in the opposite direction; that is, as the earth travels from west to east, the sun appears to travel from east to west. The earth actually ascends above the plane of the celestial equator, the sun, to the terrestrial observer, appears to descend below that plane. The earth actually descends beneath the equatorial plane, the sun appears to rise above that plane. It is more particularly with regard to the obliquity of the ecliptic compared with the celestial (perpendicular) sphere, caused by the vertical deviation of the earth's orbit from a horizontal plane, that I wish to direct your attention. Very attentive consideration will, I am sure, make plain that, even if the theory of the inclined axis could be accepted as sound, the obliquity of the ecliptic compared with the equinoctial circle must be justly attributed to parallax. Yet it would seem that the complexity arising from the artificial

character of that theory, has prevented the distinct recognition of even this almost obvious fact. I shall now be able to show you, I think, that the distinct recognition of this fact,—viz., that the apparent ascent and descent of the sun's zodiacal path is due to parallax—at once furnishes the practical astronomer with a natural standard of comparison, and a reliable means of approximately estimating the angle of variation, in the endeavour to obtain parallax of the distant stars.

If those who have printed copies of my first lecture will refer to the last part of it, they will find an appended note, entitled 'parallax of the fixed stars,' which I will now read. . . In the treatise on this subject, which forms a part of the series, entitled 'Centrifugal force and Gravitation,' we have given some reasons for conjecturing that the actual arc of vertical motion, which together with the horizontal motion compounds the earth's annual oblique orbit, is $45 \text{ deg.} \times 2 = 90^\circ$, instead of $46^\circ 55' \times 2 = 93^\circ 50'$, which is the angle obtained by past and present astronomical observation. In the treatise referred to, we suggested that a certain amount of vibratory motion in the earth's axis, in the one direction when ascending and in the opposite when descending, might be tentatively assigned as a not improbable cause of the difference between the $22\frac{1}{2}^\circ$ and the $23^\circ 27' 30''$ of observation. On further and careful consideration since the publication of the former treatise, we are quite decidedly of opinion that 45° will eventually be found to be the angle of the actual ascent and descent belonging to the earth's orbit; but, in respect to the oscillation of the Earth's

polar axis, that hypothesis should stand on its own merits, and, with the benefit of any evidence to support it, we will hold it over for consideration hereafter. If such an actual oscillation of the earth's axis be assumed, it would not effect the angle of obliquity in the sun's path as viewed from the centre of the earth. Whether, therefore, the earth's axis does or does not retain its perfect perpendicularity, throughout its orbital revolution, we attribute the whole of the supposed difference between 45° and $46^{\circ} 55'$ to parallax of (some of) the distant stars.

It has been observed by astronomers who have written on the subject, as a remarkable and, indeed, quite marvelous circumstance, that, with the extended base line of about 190 million miles, furnished by the diameter of the earth's orbit, the comparative perfection of astronomical instruments and the accuracy of modern observation have not enabled the astronomer to detect (with a few exceptions) even the smallest amount of parallax in the fixed stars. The circumstance is now generally considered to demonstrate the immensely great and almost inconceivable distance of the stars, but when the case is considered as a whole, the question suggests itself whether the failure to obtain at least some very appreciable and notable quantity of parallax does not demonstrate a want of adaptation of the means to the purpose, or a defect of some kind in the methods adopted, arising perhaps from fallacy in the theory upon which those methods are based. What is, briefly stated, the actual case? It is this:—The sun, known to be a globe of immense magnitude, of

which the diameter is about 110 times that of the earth, has, at a distance known to be somewhere about 95 million miles, its angular magnitude reduced to an apparent size of $32' 1''$. It now presents the appearance to us of a very large star, about fifty times the angular size of the planet Jupiter. There are stars differing in magnitude, some of which may be greater and some less than our sun, and some of which may be reasonably conjectured to be about equal in size to our sun. As a standard by which to compare, and to define the comparison we wish to particularize, let us take the planet Jupiter. Now if our sun were removed to one hundred times the present distance, the apparent diameter of its globe would then be less than one-half the apparent diameter of the planet Jupiter at the present time. The question is, therefore,—since we can readily calculate the very large parallax which a star, the same actual size as the sun, at a hundred times the sun's distance, would necessarily afford when viewed from the two opposite extremities of the earth's orbit,—whether we can accept a supposition that stars of not much less apparent magnitude, really afford no appreciable parallax or, if appreciable, only a parallax not exceeding some small fraction of a second. In order to put the case we are now considering in a definite and distinct shape, let us assume the angle of the earth's actual vertical motion to be, as we have stated our belief that in fact it is, 45° , and the difference between this and the observed angle $46^\circ 55'$, *viz.*, $1^\circ 55'$, to be attributable to parallax: What distance would this amount of parallax require us

to assign to a star of the first magnitude, or as the average distance of the (fixed) stars found to be subject to such an amount of parallax? The entire angle of the earth's vertical motion is (by the assumption 45°) one-half of 90° , which (90°) is the entire angle of the earth's horizontal motion, as seen from a star whose distance from the sun is equal to the distance of the earth from the sun. And $1^\circ 55'$ is about the one-thirtieth of 45×1.273 . We have, therefore, $30 \times 2 = 60$. That is, about 60 times the distance of the sun; or, in round numbers, let us say, about six thousand millions of miles, as the distance which the $1^\circ 55'$ of parallax would require us to assign. It will be asked: How could such an amount of parallax escape the observation of the practical astronomer at the present day? To which question, the answer is: The effect, in the present state of theoretical astronomy, would be to turn the celestial sphere upon the horizontal axis of the sun as a centre,* through that angle of $1^\circ 55'$. Consequently the fixed stars undergoing a uniform or corresponding parallactic displacement relatively to a point infinitely distant, the astronomical observer, who has no such absolutely fixed point to compare with, would conclude that no appreciable parallactic change had taken place †

* But if the star be situated near the equator instead of near one of the poles of the celestial sphere, the effect will be to turn the sphere horizontally upon the perpendicular axis of the Sun, through the same angle.

† It may be objected that the distant stars are not at the same or nearly the same distance; that some are far more distant than others; and that, if the less distant furnished a considerable parallax relatively to an infinitely distant point, it must be appreciable as an angular displacement between the less distant and more distant. No doubt this must be so; but this displacement is what we believe has not been subjectively looked for. The stars

Now if this last explanation of the amount of parallax which, in the case of a star the magnitude of our sun, at one hundred times the distance of the sun, would necessarily be occasioned by the change in locality of the earth in its movement from one extremity of its orbit to the opposite, has been appreciated ; it will have become evident that herein is a case in which the public has a right to require a fuller investigation of the facts, and a re-consideration of the evidence. The discrepancy or difference is enormous, in the full measure of that adjective. We have, on the one hand, the circumstance asserting itself as a fact (so to speak) that if our sun were removed to sixty times its present distance, it would present the appearance of a bright star of the first magnitude and would be subject to a parallax of not much less than 2 degrees. And yet, in the case of stars which present an appearance such as we may reasonably conjecture the sun would have at that distance, the experienced astronomical observer fails to obtain a parallax of one second, or of even less than one second. Now one *second* is the 3600th part of a *degree*, and as the difference in this case is between nearly two *degrees* and less than one *second*, it is scarcely too much to say that the practical astronomer fails to obtain even the one-thousandth part of the parallax, which, from apparently sound

selected for defining the celestial sphere and those selected for express parallactic observations, may not differ so much in distance from the Sun as to prevent their masking each other's angular displacement. (In this connection, with reference to the difficulties of parallactic observations on the fixed stars, see the paper on parallax by Lord Wrottesley in Phil. Trans. for 1851.)

theoretical considerations, we may reasonably expect some of the nearest of the so-called fixed stars will furnish, when subjectively observed with the necessary precautions for attaining their true parallax.

ABERRATION OF LIGHT.

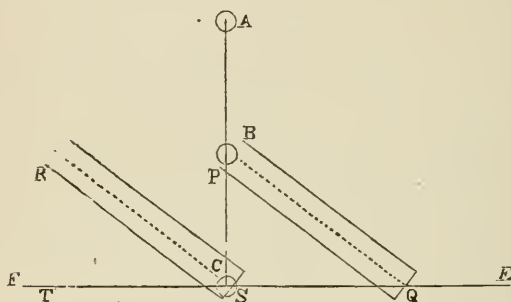
Aberration of Light as a subject may be said to be connected with that of Parallax. There may be many persons, I think, who knowing well in what the relations of the one to the other consist, consider them to be very closely connected and almost to belong to each other. But there is, to commence with, a very great and important difference between them, to which I wish to direct your particular attention. Parallax expresses the recognition by us of an actual optical fact, of an alteration in the visual angle which actually takes place if an observer, after viewing a stationary object, changes his station to another locality and again views the same stationary object. To doubt such facts of observation, or to allow such facts, when once established, to be called in question, would be to paralyze science and to put an end to the orderly progress of human knowledge. But in 'Aberration of Light' we have . . . *a theory*. Now 'a theory' is a somewhat vague and comprehensive expression. There are, indeed, theories which differ greatly in the relationship they are entitled to claim to sound science. A 'theory' may be a merely vague guess; it may be unscientific because irreconcilable with some established

fact or facts recognized by sound science. It may be not unscientific but wholly hypothetical. It may be partly certain and partly hypothetical; that is, it may be certain in respect to some of its elements and uncertain in respect to others. It may admit of demonstration: directly by positive evidence, or indirectly by negative evidence, or by circumstantial evidence. A demonstrated theory, if it be quite certain that the demonstration is sound, (which includes the certainty that it is securely based on unquestionable fact), is equivalent to a fact. Such demonstrated facts, however, before they are built permanently into the edifice of science, should be subjected to examination . . . which cannot be too strict and searching; for if one such supposed demonstrated theory be admitted as a part of the structure, and be, in fact, unsound, the security and stability of the whole is placed in jeopardy.

Aberration of Light is a theory. What rank and place amongst theories is it entitled to hold? Astronomers now consider it, and have for a long time past considered it, a demonstrated theory. Of what character is the alleged demonstration? Before replying to this question I will endeavour to put distinctly before you the meaning which those who uphold the theory attach to the term aberration, and the precise nature of the effect which they denote by that expression. As I, for myself, entirely reject the theory, it will be preferable to take the statement of the doctrine in the words of an acknowledged authority amongst astronomers, the late Sir John Herschel.

Herschel's 'Outlines of Astronomy,' page 210.

(329.) "Suppose a shower of rain to fall perpendicularly in a dead calm; a person exposed to the shower, who should stand quite still and upright, would receive the drops on his hat, which would thus shelter him; but if he ran forward in any direction, they would strike him in the face. The effect would be the same as if he remained still, and a wind should arise of the same velocity, and drift them against him. Suppose a ball let fall from a point A, above



a horizontal line EF, and at B were placed to receive it the open mouth of an inclined hollow tube PQ; if the tube were held immovable, the ball would strike on its lower side; but if the tube were carried forward in the direction EF, with a velocity properly adjusted at every instant to that of the ball, while *preserving its inclination* to the horizon, so that when the ball in its natural descent reached C, the tube should have been carried into the position RS, it is evident that the ball would, throughout its whole "descent, be found in the axis of the tube; and a spectator referring to the tube the motion of the ball, and carried along with the former unconscious of its motion, would fancy that the ball had been moving in the inclined direction RS of the tube's axis."

(330.) "Our eyes and telescopes are such tubes. In whatever manner we consider light, whether as an advancing wave in a motionless ether, or a shower of atoms traversing space (provided that in both cases we regard it as absolutely incapable of suffering resistance or corporeal obstruction from the particles of transparent media traversed by it*), if in the interval between the rays traversing the object glass of the one or the cornea of the other (*at which moment they acquire that convergence which directs them to a certain point in fixed space*), and their arrival at their focus, the cross wires of the one or the retina of the other be slipped aside, the point of convergence (which remains unchanged) will no longer correspond to the intersection of the wires or the central point of our visual area. The object then will *appear* displaced, and the amount of the displacement is *aberration*."

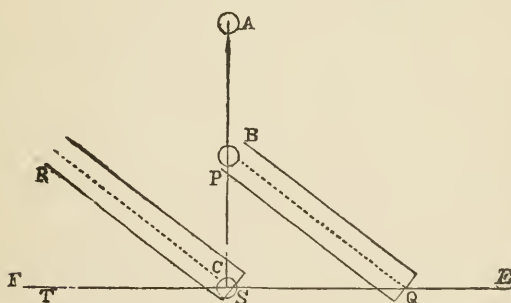
(331.) "The earth is moving through space with a velocity of about 19 miles per second, in an elliptic path round the sun, and is therefore changing the direction of its motion at every instant. Light travels with a velocity of 192,000 miles per second, which, although much greater than that of the earth, is yet not *infinitely so*. Time is occupied by "it in traversing any space, and in that time the earth describes a space which is to the former as 19 to 192,000, or

* "This condition is indispensable. Without it we fall into all those difficulties which M. Doppler has so well pointed out in his paper on Aberration. If light itself, or the luminiferous ether, be corporeal, the condition insisted on amounts to a formal surrender of the dogma, either of the extension or of the impenetrability of matter; at least in the sense in which those terms have been hitherto used by metaphysicians. At the point to which science is arrived probably few will be found disposed to mention either the one or the other."

as the tangent of $20''.5$ to radius. Suppose now APS, to represent a ray of light from a star at A, and let the tube PQ be that of a telescope so inclined forward that the focus *formed* by its object glass shall be *received* upon its cross-wire, it is evident from what has been said, that the inclination of the tube must be such as to make $PS:SQ::$ velocity of light: velocity of the earth :: $1:\tan.20''.5$; and, therefore, the angle SPQ, or PSR, by which the axis of the telescope must deviate from the true direction of the star, must be $20''.5$."

The nature of the demonstration or supposed demonstration may be now plainly distinguished; it is an inference from analogy. But, in the first place it should be remarked that in aberration of light we have an instance of a theory based primarily upon another theory: for the theory upon which *aberration* fundamentally rests is . . . that light is material and occupies time, proportional to the distance, in moving from one place to another place. In Herschel's statement, for instance, the particle or wave of light arrives at the elevated extremity of the tube; it enters the mouth of the tube; is within the tube; and, passing through the tube with a limited rapidity of motion, it makes its exit from the lower extremity of the tube, striking the eye of the observer or the ground, as the case may be. With the intention of hereafter submitting for your consideration certain objections to the fundamental theory itself, I propose to assume for the moment the material nature and stated velocity of light for the purpose of examining on their own ground that analogy by which the adherents of the theory suppose it to be supported and demonstrated.

A *shower of rain* consists of drops of water descending over an extended area. The drops succeed each other continuously for a certain time, and we may assume that they all descend at the same angle. But *light* to which we are told to consider the shower of rain analogous, does not descend in a shower of particles or waves over an extended area, but it emanates from a central point and radiates from that point in all directions. Now note the difference as it applies to Herschel's examples. Instead of a ball, let *A.*, in the figure, represent a drop of rain descending perpendicularly towards the point *S* on the plane. If, as the drop in its descent reaches the mouth *P.* of the tube, the tube be supposed to move in the direction *E.F.* with exactly the requisite velocity to enable its lower mouth *Q.* to arrive at *S.*



simultaneously with the arrival of the drop of rain at the same point, the drop will have passed through the tube without coming in contact with it. But observe that the upper mouth of the tube will now be at *R.* If a shower of rain be descending, another drop may certainly enter the tube at *R.*; but supposing the succes-

sive drops to descend from the one point *A.* only, and that their descent is confined to the line *A.P.S.*, how is a second drop to enter the mouth of the tube which has advanced to *R.*? Yet, would not this be similar to the case of light emanating from a star. Let the star be directly over *A.* in the line *S.P.A.*, and let the ray or rays of light enter the mouth of the moving tube, in the manner supposed by Herschel, at *P.*, how are successive rays to enter the mouth of the tube at *R.*? Rays of light from the star will no doubt arrive at *R.*; but is it not evident that they cannot arrive from the star, which has remained stationary, at the same angle at which they arrived at *P.*? If the light arrived vertically at *P.* it must arrive with some degree of obliquity at *R.*, and cannot enter the tube unless the angle of the tube's elevation be changed accordingly. Should it be replied to this: the distance of the star from the earth is so very great that the earth's motion is insufficient to sensibly affect the angle of incidence of the light from the star: then, the reply destroys the theory as illustrated by Herschel; for if the orbital motion of the earth continued for several months be insufficient to sensibly affect the angle of incidence, that same orbital motion during the minute interval of time which, according to the theory, the light occupies in passing through the telescope tube cannot surely affect the angle of incidence, and therefore cannot necessitate an alteration in the angle of elevation of the telescope tube. The question is evidently reduced to one of impact, the supposed case does not belong at all to compounded motion, but to a supposition of compounded

force resulting from two independent motions.* It may be allowed that as a supposed case belonging to the composition of force, if the materiality of light be admitted, there may be standing-room on the theory for an argument, and owing to the wholly hypothetical character of the theory, the demonstration of its fallacy by such argument might be, to say the least, difficult. I have endeavoured elsewhere to show in what manner the reality of the supposed aberration of light may be astronomically subjected to experiment.

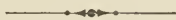
*In considering Herschel's illustration the case may be simplified by conceiving the tube long enough to reach from the earth to the star. Cut off the terrestrial end of the tube within a few feet of the observer's eye, and call it a telescope; the telescope will be directed towards the place of the star, not towards a place at an angular distance of $20''$ away from it.

LECTURE THIRD.

THEORIES OF LIGHT

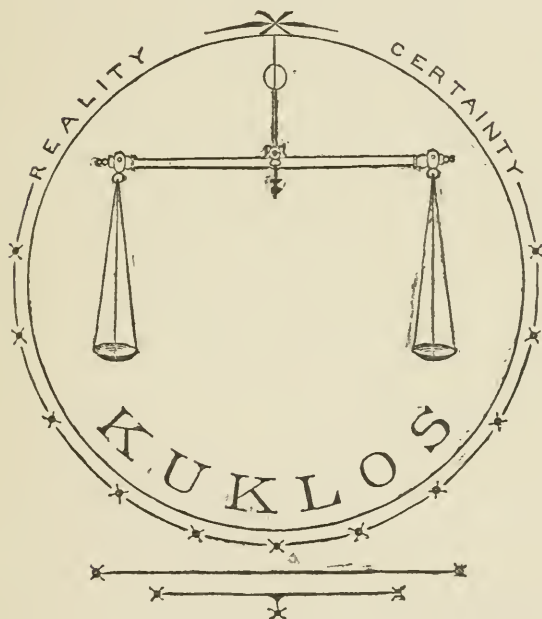
BASED ON

ASTRONOMICAL OBSERVATION.



BY

JOHN HARRIS.



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LECTURE THIRD.

INTRODUCTORY OBSERVATIONS.

In continuing an argument that certain mistakes of a serious character exist at the present time in the theories of Physical Science, and in proceeding to specify those mistakes, I would remark, assuming that my argument will be substantiated, that no immediate source of danger to which modern science is exposed exceeds that arising from the supposition that human science, at the present or any other epoch in the progress of human knowledge, is bound to account with certainty and decision for every difficult problem and mysterious phenomenon which is brought under its consideration. To conceive, form and construct a tentative assumption or theory, if the assumption or theory be scientifically constructed, is certainly quite legitimate. To push the theory as far onwards as existing knowledge will enable us, so as to intelligibly interrogate nature as to the facts, is also quite legitimate and necessary in order that progress towards the completion and perfection of science may be made. But...to suppose it necessary that a theory on a complex and difficult subject must at once be made complete and adopted as a constituent part of established science, or to suppose that science is bound to admit a theory as sound because, at the time it is proposed, no more satisfactory explanation can be given of the facts, is to go astray from the legitimate path of science. Far advanced as the present station of human knowledge may be compared with what it was a few centuries since, we cannot be too careful to remember that modern Science was inaugurated by Francis Bacon's system, and that the 'Novum Organum' of that author may be correctly described as an expansion and application of the caution, with which it commences, . . . *to beware of idols*. The *εἰδωλα* of the present age are the same as the *εἰδωλα* of Bacon's time, but they have the faculty of adapting themselves to every age and every degree of educational development. Those which come to the highly educated and experienced philosopher in his study, do not

come in the same guise and with the same arguments as when the raw and inexperienced student is to be subjected to their persuasions. Coming professedly in the name of science, with all the advantages which a consummate knowledge of scientific method and the refinement of false analogy and sophistry can bestow, the danger to the former is perhaps not so much less as he is apt to imagine.

THEORIES OF LIGHT BASED ON ASTRONOMICAL OBSERVATION.

The Theories of Light which are directly based on astronomical observation are two. . . Aberration of Light. . . and. . . Velocity of Light. As already stated in my last lecture, however, the theory of Aberration is fundamentally based upon that of Velocity of Light. The primary reasons why, in my judgment, the theory of Aberration must, even on its own ground, be condemned as untenable, have been put before you. There are two rival theories on the nature of light. . . the Corpuscular. . . and Undulatory theories. . . which, although not based on astronomical observation, are so connected with the Velocity-of-Light theory, that it will be only proper to give some attention to them before entering upon the consideration of the latter. Both these theories, of the nature of light, may be correctly considered to be in the same case as the Aberration theory. I do not mean by this that, assuming the Aberration theory is shown to be unsound and merely notional, either of the others would *therefore* necessarily become untenable. The connection is not of that kind. But all three are in the same case in such wise that all three are *material dynamic theories* : each of them assumes the nature of light to be material, and the effect, called *light or illumination*, to be occasioned by a kind of matter, or the motion of a kind of matter which moves from the luminiferous body to the illumi-

nated body with velocity, (or by an undulation which is propagated through and by means of material particles, and which undulation has velocity.)

Like the Aberration theory, therefore, both these theories of the nature of light are primarily dependent for support upon the soundness of the Velocity-of-Light theory, for this latter theory is the basis upon which each of them rests.

(1.) *The Corpuscular Emission Theory.*

A theoretical explanation of the observed phenomena belonging to the subject of light, proposed by Sir Isaac Newton, is known as Newton's emission theory, or as it is sometimes called, the corpuscular theory of light.

The following is the statement of the most important propositions contained in it:

From *Lardner's Natural Philosophy.*

1222. "*Corpuscular Theory.*—In the corpuscular theory, which was adopted by Newton as the basis of his optical enquiries, light is considered as a material substance, consisting of infinitely minute molecules which issue from luminous bodies and pass through space with prodigious velocities. Thus, in this hypothesis, the sun is regarded as a source from which such molecules or corpuseles proceed in every direction, with such a velocity that they pass from that luminary to the earth, over a distance of ninety-five millions of miles in about eight minutes and thirteen seconds.

This immense velocity with which they are endued, amounting to nearly two hundred thousand miles per second, united with the fact established by observation, that they do not impress with the slightest momentum the

“lightest objects which they strike, render it necessary to suppose that they are so minute as to be altogether destitute of inertia or gravity. The strongest beam of sunlight acting upon the most delicate substance, upon the fibres of silk or the web of the spider, or upon gold leaf, does not impress upon them the slightest perceptible motion. Now, in order that a particle of matter, endued with a velocity so great, should have no perceptible momentum, it is necessary to suppose it to be almost infinitely minute.

But this minuteness requires to be admitted to a still greater extent; when it is considered that particle after particle, striking upon bodies so light, even after the communication of their forces, impart to them no perceptible motion.

1223. “*Difference of colour explained.*—In this system the difference of colour which prevails among the different homogeneous lights, the combination of which constitutes solar light, is ascribed to different velocities.

Thus the sensation of red is produced by luminous molecules animated by one velocity, orange by another, blue by another, and so on.”

1224. “*Laws of refraction and reflection explained.*—The law which renders the angle of reflection equal to the angle of incidence, is explained by supposing such molecules to have perfect elasticity. The law of refraction is explained by supposing that such molecules are subject to an attraction towards the perpendicular when they enter a denser, and by a repulsion from it when they enter a rarer medium.”

Objections to the Corpuscular Theory.

Taking the statement of the theory just quoted. “In the corpuscular theory, which was adopted by Newton as the basis of his enquiries, light is considered as a material substance, consisting of infinitely minute molecules which issue from luminous bodies and pass

through space with prodigious velocities." It necessarily follows, as a corollary, that when the sun has continued to shine for any length of time on a body which absorbs the light, a certain appreciable amount of the material projected from the sun, as light, will remain in that body, by which the gravity and mass of the body will be increased. Now if this actually happened it could not long remain unnoticed. Lardner himself remarks, in reference to the hypothetical particles which, according to the theory, issue from luminous bodies, it is necessary to suppose that they are so minute as to be altogether destitute of inertia or gravity: "The strongest beam of sunlight acting upon the most delicate substance, upon the fibres of silk, or the web of the spider, or upon gold-leaf, does not impress upon them the slightest perceptible motion. Now, in order that a particle of matter endued with a velocity so great should have no perceptible momentum, it is necessary to suppose it to be almost infinitely minute." It is evident that Dr. Lardner, in writing this, must have been misled by the theory itself and the authority of Newton into stating a supposition which it is not scientifically permissible to entertain. By the expression particles almost infinitely minute is meant particles extremely small, *i. e.*, particles of very small size. But the gravity of a material substance, whatever its size may be, cannot be got rid of by dividing and sub-dividing it into very small or into extremely minute parts; its gravity cannot in such a manner be even lessened. The sum of the gravities of the very small, or of the extremely minute parts will exactly make up the gravity which the entire body possessed, previously to its division. Take, for in-

stance, a pound by weight of any substance, and suppose it to be divided into a million parts, each of the parts being exactly similar and of the same size; then, each of those parts will weigh the one millionth of a pound, and, if one of them were to be again divided into a thousand parts, then one of those products of the sub-division would weigh the one thousandth of the millionth of a pound. The last particles would be very small, but nevertheless, if a thousand millions of them were projected by the sun in the course of an hour on to any one particular spot, a quantity of the material amounting to a pound in weight thereof would be the aggregate product at the end of that time. And again, how is matter, whether the particles be large or small, to move with an enormous velocity without having or acquiring momentum? *Gravity*, when motionless, [*i. e.*, when restrained from moving] and *momentum*, when in motion, are two of the characteristic properties of *matter*, by which is meant *some material thing* whether it be an aggregated mass of enormous bulk, such as the planet Jupiter, or the most minute particle that can be imagined. Dr. Lardner also states that: "The law of refraction is explained by supposing that such molecules are subject to an attraction towards the perpendicular when they enter a denser, and by a repulsion from it when they enter a rarer medium." Now this is no explanation in a scientific sense; so far from it, such a supposition is inadmissible unless supported by some proof or evidence outside the theory. There is no support in this case, but on the contrary the suggestion is quite gratuitous and altogether improbable. Why should a molecule of

matter be attracted by a perpendicular to a denser, or be repelled by a perpendicular to a rarer, medium ?

It has been long since established as a fact, by the results of numerous careful experiments and observation, that a ray of light, on entering a denser from a rarer medium is refracted towards a perpendicular to the surface at which it enters, and, on entering a rarer from a denser medium, is refracted from a perpendicular to the surface of the rarer medium, at which it enters. When asked to give a reason, it is scientifically correct to say in reply, that it is according to, or in obedience to, the law of the refraction of light, which is recognized as an established law belonging to the science of Optics, because demonstrated by the observed facts, of which, or from which, it may be said to be a generalization. But when we wish to proceed further, and to explain the particular nature and properties of the ray of light which is so refracted, and to refer the law of the refraction of light to a more general or primary law, and thus to explain *particularly* the cause of the ray being refracted according to the law, it will not then be in accordance with the rules of sound science to invent a cause expressly for the purpose of the explanation; namely, to suppose a unique cause unsupported by experimental evidence or by analogy; such, for example, as a force elsewhere unknown or unrecognized, or a known force as acting in a manner unprecedented and elsewhere unobserved. To do this would be not to explain, but to build up prejudice in the way of scientific explanation. If more sound and certain knowledge cannot be obtained on a particular subject, it is unadvisable to dilute with uncertain, and worse than useless to vitiate with false

and unsound knowledge, that which we do already possess.

(2.) *The Undulatory Theory.*

In consequence of the corpuscular emission theory being found insufficient to satisfactorily explain some of the more recently observed phenomena of light, belonging in particular to what is termed *interference*, it has been generally given up, and, in its place, the undulatory theory of light has been adopted as the recognized basis of optical science. The undulatory theory is of almost the same age as the emission theory of Newton, having been first proposed and adopted by Hooke and Huygens, contemporaries of Newton; it is only, however, since the commencement of the present century that this theory has been more completely developed, and still more recently that it has been generally (now, almost unanimously) adopted. This theory is also sometimes called the wave-theory of light, and it has been primarily derived from what is known as the wave-theory of sound*, light being considered as the effect of an undulation or agitation propagated through and by means of the particles of a subtle and extremely elastic fluid called *ether*; analagous to the effect of the wave agitations of the particles of air, or other gaseous fluid, which according to the wave-theory is recognized as causing the effect, or class of effects, denominated sound.

Lardner's Natural Philosophy.

1225. "*Undulatory Theory.*—In the undulatory theory which was adopted by Huygens, and after him by most continental philosophers, light is regarded as in all respects analagous to sound.

“The luminous body in this system does not transmit any matter through space any more than a bell transmits matter when it sounds. The luminous body is regarded as a centre of vibration; but in order to explain the transmission of this vibration through space, the existence of a subtle fluid is assumed, which plays, with regard to light, nearly the same part as the atmosphere plays with regard to sound. The sun, in this theory, then, is a centre of vibration, and the space which surrounds him being filled with an atmosphere of this subtle fluid, transmits this vibration exactly as the atmosphere transmits the vibration of a sounding body.”

1226. “*The Luminous Ether*.—This hypothetical fluid has received the name of *ether*. It is supposed not only to fill all the vacant spaces of the universe which are unoccupied by bodies, but also to fill the interstices which exist between the component parts of bodies. Thus it is not only mingled with the atmosphere which surrounds the earth, but also with the component parts of water, glass, and all transparent substances; and since opaque substances, when rendered sufficiently thin, are penetrable more or less by light, it is necessary to admit that it also fills the pores of such bodies. If this luminous ether did not prevail throughout the whole extent of the atmosphere, the light of the stars could not reach our eyes. If it did not exist in water, glass, precious stones, and all transparent substances, these substances could not be penetrable by light as they are; in fine, if it did not exist in the humours of the eye, light could not affect this organ, and the undulations could not reach the membrane of the retina.”

1227. “*Effects ascribed to its varying density*.—But although this luminous ether is thus assumed to be omnipresent, it does not everywhere prevail with the same density: It is probable that its density in the celestial spaces which intervene between planet and planet is the

“same which it has under the exhausted receiver of an air-pump or above the mercurial column in a barometer.

But its density in transparent media must be different, because to explain the phenomena of light passing through them it is necessary to suppose that the undulations change their magnitude, a supposition which is only compatible with a change in the elasticity of the ether. We shall see further, that in some transparent bodies existing in a crystallized state it is necessary to suppose also that the density of the ether in different directions in the same medium varies.

If this universal ether were for a moment in a state of perfect repose, the universe would be in absolute darkness; but the moment its equilibrium is disturbed, and that an undulation or vibration is imparted to it, that instant light is created, and is propagated indefinitely on all sides, as, in an atmosphere perfectly tranquil, the vibration of a musical string or the sound of a blow is propagated to a distance in all directions according to determinate laws.

Light itself, must not, however, be confounded with the ether which is the medium of its propagation. Light is no more identical with the hypothetical ether than sound is identical with air. The ether, in the one case, and the air in the other, are merely the media by which the systems of undulations which constitute the real sense of light and sound are propagated.”

1228. “*Analogy of light and sound.*—In considering the analogy between light and sound, however, there is an important distinction which must not escape notice. Sound is propagated, not only by undulations transmitted through the air, but also by undulations transmitted through other fluids as well as solids, as has been already explained. Light, however, according to the undulatory theory, is transmitted only by the undulations of the luminous ether. Light, therefore, does not pass through a transparent body, such as glass, in the same manner as sound is transmitted

through the same body. The undulations by which sound is propagated through the air would be imparted to glass itself, which will continue them and transmit them to another portion of air, and thence to the ear ; but when the undulations of light are transmitted through glass or any other transparent medium, they must be supposed to be propagated, not by the vibration of the glass itself, but by the vibration of the subtle ether which pervades its pores."

Objections to the Undulatory Theory.

The Ether.—The supposed fluid thus named is usually spoken of by writers on optics as a hypothetical fluid ; but such a use of the expression 'hypothetical' is apt to mislead. . . if the writer, who so uses the word, supposes at the same time that the undulatory theory of light is scientifically established. If the expression 'hypothetical' is merely intended to indicate that the supposed subtle fluid, the ether, cannot be directly taken cognizance of by the senses, its use is objectionable ; because many natural as well as all ideal facts are in the same case. . . that is, they cannot be directly cognized by the senses. A belief that the undulatory theory of light is scientifically established, should include the belief that the existence of the ether is demonstrated by the observed facts and the legitimate reasoning belonging to that theory. If the *non-existence* of the ether fluid were to be demonstrated, the undulatory theory of light, which is based upon its assumed existence, would necessarily have to be given up ; and therefore if, or so long as, the existence of the ether is in any degree doubtful, so long must the theory itself be in doubt, and must not be considered as scientifically established—merely a theory, not a demonstrated theorem. The expression 'subsensible' as applied by Prof. Tyndall to the (supposed) ether fluid is much preferable to 'hypothetical' ;

if the theory *is accepted* as demonstrated. In Dr. Lardner's statement of the undulatory theory, quoted at page 15, a concise explanation of the supposed nature of the luminous ether will be found. Also in Prof. Tyndall's Lectures on Light, (*See Appendix,*) wherein the sound and light-waves are compared, the material and gaseous nature of the subsensible fluid is very distinctly assumed: "Could you see the air through which sound-waves are passing, you would observe every individual particle of air oscillating to and fro." "Could you see the ether, you would also find every individual particle making a small excursion to and fro." The general object of this part of the lecture is to show the analogy between light and sound; but we can scarcely be incorrect in supposing that the more particular object is to demonstrate the existence of the subsensible ether-fluid by thus showing and illustrating the analogy.

A difficulty of a kind to make extreme caution necessary as to accepting the existence of the ether, until strictly demonstrated, is that the theory, and the observed facts belonging to it, together necessitate the assumption that the material subsensible fluid occupies all space, and that all other descriptions of matter, not absolutely opaque, must be considered porous, and as having their interstices all filled with ether. The supposition of all space being filled with a material fluid for the purpose of producing effects at certain distant points, or, in other words, an omnipresent material fluid filling and pervading the universe for the production of one class, or kind of effect, only, does not seem to harmonize with the

directness and simplicity of the methods employed in other parts of the work of creation. Notwithstanding the supposed attenuated subsensible characteristics of the fluid, the inconceivably enormous quantity of material required by the theory at once suggests improbability. If, however, the objection went no further than this, it might perhaps be answered with some degree of force by supposing that the ether fulfils some other purpose, or purposes, with which we are as yet altogether unacquainted; but the objection does go much further, because of the *nature* of the ether fluid—assumed by the theory to be material, and on which assumption the theory rests. Why, then, does not the ether, in obedience to the general law known to govern, and recognized as universally governing, matter, collect around the centres of gravitating influence? Are we asked to suppose the ether to differ from all other varieties of matter, to be exempt from the influence of gravitation, and at the same time to have other properties in common with the other descriptions, and to be controlled by some of the laws governing other kinds of matter; as, for example, to possess the property of elasticity, and to be capable of propagating an impulse by undulations of its particles? Very much of the sound natural science now possessed by us is based on the certain knowledge that *gravitation* is a general law governing all matter. If this is uncertain, or is to be considered uncertain and open to controversy, where, then, are we to find scientific certainty in respect to the material world? If any one variety of matter may be exempt from such a general law, so also may other

varieties. If the reply to this should be . . . well, then, the ether in that sense is not material; it is evident that the undulatory theory of light must at once fall to the ground, because it rests upon the assumption that the ether is a material fluid, possessing (some of) the properties belonging essentially and distinctively to all matter.

There remains to be stated another objection to the theory, which, although independently calling for satisfactory explanation, is at the same time so allied to and connected with the foregoing as to further increase its force. I allude to the kindred phenomena of radiant heat. The nature of this particular difficulty may be thus briefly stated:—The phenomena of light and of radiant heat are so analogous, so evidently allied and similar to each other, in many respects, that it is almost, if not quite, impossible, in a reasonable sense, to suppose the one effect (or class of effects) to result from the undulation of an elastic material fluid and not to suppose the other effect (or class of effects) to be produced in the like manner; but although there are very close analogies between the two kinds of effect (or classes of phenomena) in some respects, there are also differences of an essential and distinctive character, such that a very grave difficulty must be felt as to admitting even a theoretical supposition that a mere variation in the velocities of undulations in the same fluid can occasion them. That is to say, the difference in the characteristics of light and radiant heat are too great, and of essentially too distinctive a kind, to allow the supposition that a certain number of undulations or vibratory pulses of ether, taking place in a second of time may produce light, and that a certain lesser (or

greater) number of vibratory pulses, in a second, may be productive of radiant heat. What is the alternative?.. Are we to suppose the existence of two different omnipresent ethers?

A final objection to the undulatory theory is the demand, which it necessarily makes upon those who accept it, to suppose all space to be filled with matter oscillating with inconceivable rapidity. Yet this is not nearly the whole difficulty; it has to be supposed that distinct oscillations from every source of light and from every visible object are crossing each other in every possible direction. To accept a supposition that waves are propagated in and through a material fluid at the rate of from 450 to nearly 800 millions . . . per second of time; and that these waves are continually crossing each other without destroying, damaging, or affecting the individuality of each other, is to accept a supposition which appears to be extravagant and unreasonable in a very high degree.

The Velocity-of-Light Theory.

We have in this to consider a theory now just two hundred years old, which originated as an hypothesis constructed by the imagination to account for an astronomical fact then first observed and for which no assignable cause presented itself. The following brief but careful summary of the case, quoted from Sir John Herschel's treatise, will first serve as an authoritative statement of the origin of the theory, and of the present position occupied by it as belonging to astronomical science.

Herschel's Outlines of Astronomy.—“(545.) The earth's orbit being concentric with that of Jupiter and interior to it, their mutual distance is continually varying, the variation extending from the *sum* to the *difference* of the radii of the two orbits; and the difference of the greater and least distances being equal to a diameter of the earth's orbit. Now, it was observed by Roemer, (a Danish astronomer, in 1675), on comparing together observation of eclipses of the satellites during many successive years, that the eclipses at and about the opposition of Jupiter (or its nearest point to the [earth) took place *too soon*—sooner, that is, than, by calculation from an average, he expected them; whereas those which happened when the earth was in the part of its orbit most remote from Jupiter were always too late. Connecting the observed error in their computed times with the variation of distance, he concluded, that, to make the calculation on an average period correspond with fact, an allowance in respect of time behoved to be made proportional to the excess or defect of Jupiter's distance from the earth above or below its average amount, and such that a difference of distance of one diameter of the earth's orbit should correspond to 16m. 26s. .6 of time allowed. Speculating on the probable physical cause, he was naturally led to think of a gradual instead of an instantaneous propagation of light. This explained every particular of the observed phenomenon, but the velocity required (192,000 miles per second) was so great as to startle many, and, at all events, to require confirmation. This has been afforded since, and of the most unequivocal kind, by Bradley's discovery of the aberration of light. The velocity of light deduced from this last phenomenon differs by less than one eightieth of its amount from that calculated from the eclipses, and even this difference will no doubt be destroyed

“ by nicer and more rigorously reduced observations. The velocity has also been determined by M. Fizeau (by direct experiments with a reflecting apparatus on a most ingenious principle, suggested by Sir C. Wheatstone for measuring the velocity of the electric current) at 70,000 geographical leagues, 25 to the degree = 194,000 statute miles per second.”

Having regard to the great importance of correctly appreciating the actual circumstances of the case, we will quote also the history of this (assumed) discovery or observation as given by Dr. Lardner.

Lardner's Astronomy.

(2959). “ *Motion of light discovered and its velocity measured.*—Soon after the invention of the telescope, Roemer, an eminent Danish astronomer, engaged in a series of observations, the object of which was the discovery of the exact time of the revolution of one of these bodies around Jupiter. The mode in which he proposed to investigate this was by observing the successive eclipses of the satellites, and noticing the time between them.

Now if it were possible to observe accurately the moment at which the satellite would, after each revolution, either enter the shadow or emerge from it, the interval of time between these events would enable us to calculate exactly the velocity and motion of the satellite. It was, then, in this manner that Roemer proposed to ascertain the motion of the satellite. But, in order to obtain this estimate with the greatest possible precision, he proposed to continue his observations for several months.

Let us, then, suppose that we have observed the time which has elapsed between two successive eclipses, and that this time is, for example, forty-three hours. We ought to expect that the eclipse would recur after the lapse of every successive period of forty-three hours.

“Imagine, then, a table to be computed in which we shall calculate and register before hand the moment at which every successive eclipse of the satellite for twelve months

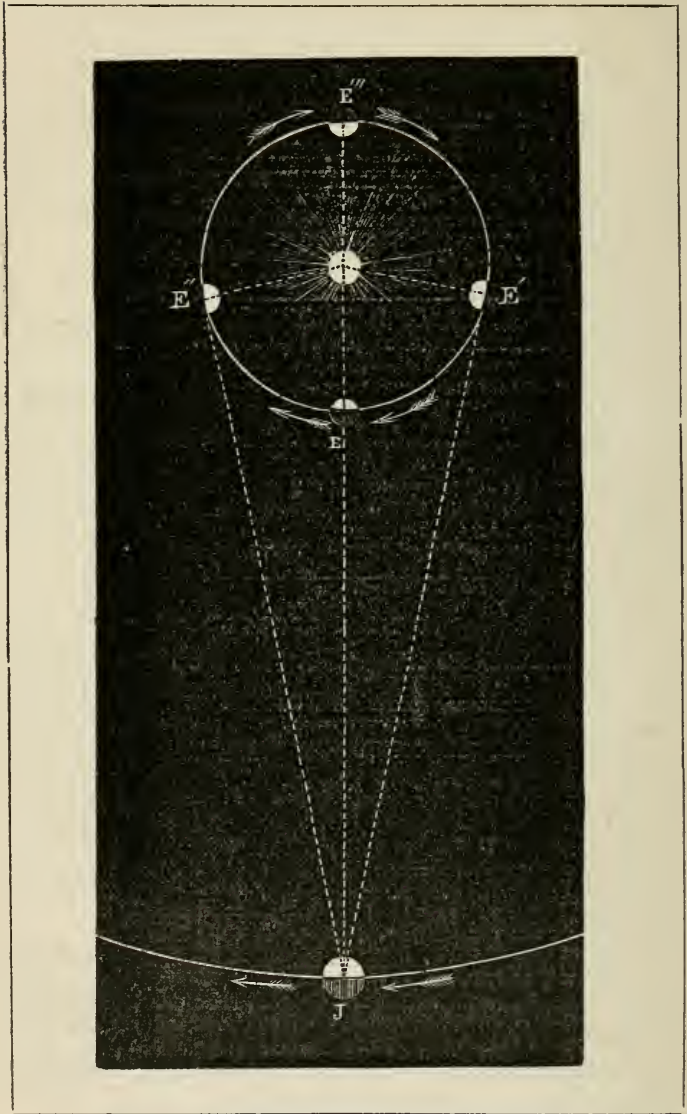


Fig. 756.

“to come shall occur, and let us conceive that the earth is at A , at the commencement of our observations; we shall then, as Roemer did, observe the moment at which the eclipses occur, and compare them with the moments registered in the table.

“Let the earth, at the commencement of these observations, be supposed at E . fig. 756, where it is nearest to Jupiter. When the earth has moved to E' , it will be found that the occurrence of the eclipse is *a little later* than the time registered in the table. As the earth moves, from E ." towards E ."', the actual occurrence of the eclipse is more and more retarded beyond the computed occurrence, until at E ." in conjunction, it is found to occur about sixteen minutes later than the calculated time.”

“By observations such as these, Roemer was struck with the fact that his predictions of the eclipses proved in every case to be wrong. It would at first occur to him that this discrepancy might arise from some errors of his observations; but, if such were the case, it might be expected that the result would betray that kind of irregularity which is always the character of such errors. Thus, it would be expected that the predicted time would sometimes be later, and sometimes earlier, than the observed time, and that it would be later and earlier to an irregular extent. On the contrary, it was observed, that while the earth moved from E . to E ."', the observed time was continually later than the predicted time, and moreover, that the interval by which it was later continually and regularly increased. This was an effect, then, too regular and consistent to be supposed to arise from the casual errors of observation, it must have its origin in some physical cause of a regular kind. The attention of Roemer being thus attracted to the question

“ he determined to pursue the investigation by continuing to observe the eclipses. Time accordingly rolled on, and the earth, transporting the astronomer with it, moved from E''' to E' . It was now found, that though the time observed was later than the computed time, it was not so much so as at E''' , and, as the earth again approached opposition, the difference became less and less, until, on arriving at E , the position of opposition, the observed eclipse agreed in time exactly with the computation. From this course of observation it became apparent that the lateness of the eclipse depended altogether on the increased distance of the earth from Jupiter. The greater that distance, the later was the occurrence of the eclipse as apparent to the observer, and on calculating the change of distance, it was found that the delay of the eclipse was exactly proportional to the increase of the earth's distance from the place where the eclipse occurred. Thus, when the earth was at E''' the eclipse was observed sixteen minutes, or about 1000 seconds, later than when the earth was at E . The diameter of the orbit of the earth E . E''' measuring about two hundred millions of miles, it appeared that that distance produced a delay of a thousand seconds, which was at the rate of two hundred thousand miles per second. It appeared, then, that for every two hundred thousand miles that the earth's distance from Jupiter was increased, the observation of the eclipse was delayed one second.

Such were the facts which presented themselves to Roemer. How were they to be explained? It would be absurd to suppose that the actual occurrence of the eclipse was delayed by the increased distance of the earth from Jupiter. These phenomena depend only on the motion of the satellite and the position of Jupiter's shadow, and

“ have nothing to do with, and can have no dependence on, the position or motion of the earth, yet unquestionably the time they *appear* to occur to an observer upon the earth, has a dependence on the distance of the earth from Jupiter.

To solve this difficulty, the happy idea occurred to Roemer that the moment at which we see the extinction of the satellite by its entrance into the shadow is not, in any case, the very moment at which ~~that~~ event takes place, but some time afterward, viz., such an interval as is sufficient for the light, which left the satellite just before its extinction, to reach the eye. Viewing the matter thus, it will be apparent that the more distant the earth is from the satellite, the longer will be the interval between the extinction of the satellite and the arrival of the last portion of light, which left it, at the earth; but the moment of the extinction of the satellite is that of the commencement of the eclipse, and the moment of the arrival of the light at the earth is the moment the commencement of the eclipse is observed.

Thus Roemer, with the greatest felicity and success, explained the discrepancy between the calculated and the observed times of the eclipse; but he saw that these circumstances placed a great discovery at his hand. In short, it was apparent that light is propagated through space with a certain definite speed, and that the circumstances we have just explained supply the means of measuring that velocity.

We have shown that the eclipse of the satellite is delayed one second more for every two hundred thousand miles that the earth's distance from Jupiter is increased, the reason of which obviously is, that light takes one second to move over that space; hence it is apparent that the velocity of light is at the rate, in round numbers, of two hundred thousand miles per second.

“ By more exact observation and calculation the velocity is found to be 192,000 miles per second, the time taken in crossing the earth's orbit being 16*m.* 26. 6*s.*”

In both the preceding accounts of the origin of the velocity-of-light theory; the eclipse of the Satellite is spoken of as simple and uniform in its character. There is no indication that the phenomenon referred to can only be considered simple if the expression ‘eclipse’ be used in the restricted and distinctive sense.

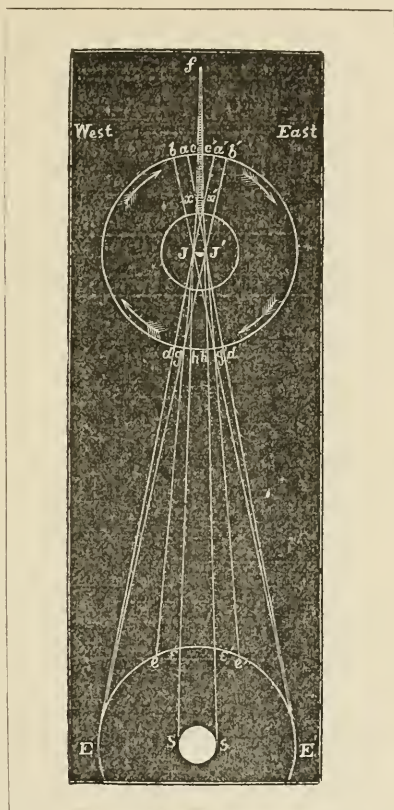
The astronomer, as will presently appear, distinguishes an eclipse from an occultation; but in ordinary language, and also in the language of astronomy when no [particular reason is perceived for distinguishing the character of an eclipse, that expression (eclipse) is made use of to denote an occultation by the interposition of the planet itself between the observer and the body observed, as well as extinction of the body's visibility by immersion into the shadow of the planet. (For example: a so-called eclipse of the sun by the moon.)

It is so imperative in this case that the difference between the eclipse, in the restricted sense,[‡] and the occultation, should be clearly understood, and that the data for deciding whether the eclipse, spoken of in the preceding narratives of Roemer's observations,[‡] refers to the simple or to the compound phenomenon, that we feel it requisite to quote in particular detail the description of the eclipse and occultation phenomena given by the same two authorities, Lardner and Herschel respectively.*

* Herschel's description of the phenomena will be found as an Appendix at the conclusion.

Eclipses, Transits, and Occultations of the Jovian System.

(2950) "The motions of Jupiter and his satellites, as seen from the earth, exhibit, from time to time, all the effects of interposition. Let *J. J'*. fig. 810, represent



the planet, *J. f. J'* its conical shadow, *S. S*, the sun, *E.* and *E'* the positions of the earth when the planet is in quadrature, in which position the shadow *J. f. J'* is presented with least obliquity to the visual line, and therefore least foreshortened, and most distinctly seen. Let *b. b. d. d'* represent the orbit of one of the satellites, the

“ plane of which coincides nearly with that of the planet's orbit, and, for the purposes of the present illustration, the latter may be considered as coinciding with the ecliptic without producing sensible error. From E . suppose the visual lines $E. J.$ and $E. J'$ to be drawn, meeting the path of the satellite at $d.$ and $g.$, and $a.'$ and $b.'$, and in like manner, let the corresponding visual lines from E' meet it at $d.'$ and $g.'$ and at $a.$ and $b.$ Let $c.$ and c' , be the points where the path of the satellite crosses the limits of the shadow, and $h.$ and h' , the points where it crosses the extreme solar rays which pass along those limits.

“ If l express the length Jf of the shadow, d the distance of the planet from the sun in semi-diameters of the planet, and r and r' the semi-diameters of the sun and the planet respectively,

$$\begin{aligned} \text{we shall have (2917) } l &= d \times \frac{r'}{r-r'} \\ \text{But } d &= 11227 \quad r = 441000 \quad r' = 44000 \\ &\qquad\qquad\qquad 44 \\ \text{and therefore } l &= 11227 \times \frac{44}{441-44} = 1247^* : \end{aligned}$$

that is to say, the length of the shadow is 1247 semi-diameters of the planet. Now, since the distance of the most remote satellite is not so much as 27 semi-diameters of the planet (2760), and since the orbits of the satellites are almost exactly in the plane of the orbit of the planet, it is evident that this will necessarily pass through the shadow, and almost through its axis, every revolution, and the lengths of their paths in the shadow will be very little less than the diameter of the planet.

“ The fourth satellite, in extremely rare cases, presents an exception to this, passing through opposition without entering the shadow. In general, however, it may be considered that all the satellites in opposition pass through.”

* Qy. 1244.

(Note. This last statement about the fourth satellite appears very remarkable in connection with that which precedes it, and with the great breadth of the shadow. But if we assume a moderate amount of vertical deviation above and below the orbital plane of the planet's equator, it becomes quite intelligible why the fourth satellite sometimes passes through opposition without entering the shadow.

(2951). "Effects of interposition.—The planet and satellites exhibit, from time to time, four different effects of interposition."

(2952). "1st. *Eclipses of the Satellites*.—These take place when the satellites pass behind the planet. Their entrance into the shadow, called the *immersion*, is marked by their sudden extinction. Their passage out of the shadow, called their *emersion*, is manifested by their being suddenly re-lighted."

(2953). 2nd. "*Eclipses of the Planet by the Satellites*.—When the satellites, at the periods of their conjunctions, pass between the lines SJ , and $S'J'$, their shadows are projected on the surface of the planet in the same manner as the shadow of the moon is projected on the earth in a solar eclipse, and, in this case, the shadow may be seen moving across the disk of the planet, in a direction parallel to its belts, as a small round and intensely black spot."

(2954). 3rd. "*Occultations of the Satellites by the Planet*.—When a satellite, passing behind the planet, is between the tangents $EJ.a'$, and $EJ.b'$, drawn from the earth, it is concealed from the observer on the earth by the interposition of the body of the planet. It suddenly disappears on one side of the planet's disk, and as suddenly reappears on the other side, having passed over that part of its orbit which is included between the tangents. This phenomena is called an occultation of the satellite."

(2955). “*Transit of the Satellites over the Planet.*—When a satellite, being between the earth and planet, passes between the tangents $E.J.$ and $E'.J'$, drawn from the earth to the planet, its disk is projected on that of the planet, and it may be seen passing across, as a small brown spot, brighter or darker than the ground on which it is projected, according as it is projected on a dark or bright belt. The entrance of the satellite upon the disk, and its departure from it, are denominated its *ingress* and *egress*.”

(2956). “*All these phenomena manifested at quadrature.*—When the planet is in quadrature, and the shadow therefore presented to the visual ray with least effect of foreshortening, all these several phenomena may be witnessed in the revolution of each satellite.

The earth being at $E.$ or $E'.$, the visual line $E.J.$ or $E'.J'$ crosses the boundary $x.'$ or $x.$ of the shadow at a distance $x'.J.$, or $x.J.$, from the planet, which bears the same ratio to its diameter as the distance of Jupiter from the sun bears to the distance of the earth from the sun, as is evident from the figure. But Jupiter's distance from the sun being five times that of the earth, it follows that the distance $x.J.$ is five diameters, or ten semi-diameters, of the planet. But since the distance of the first satellite is only six, and that of the second somewhat less than ten, semi-diameters of the planet, it follows that the paths of these two will lie within the distance $x.J.$ or $x'.J'$.

The planet being in quadrature 90° behind the sun, the earth will be at $E.$, and the entire section $c.c'$ of the shadow at the distances of the third and fourth satellites (which are 15 and 27 semi-diameters of the planet, respectively,) will be visible to the west of the planet, so that when these satellites, moving from b , as indicated by the arrow, pass through the shadow, their immersion and

“emersion will be both manifested on the west of the planet, by their sudden disappearance and reappearance on entering and emerging from the shadow at c . and c' . But the section of the shadow, at the distances at the first and second satellites, being nearer to the planet than $x.x'$ will be visible only at its western edge, the planet intercepting the visual ray directed to the eastern edge. The immersion, therefore, of these will be manifested by their sudden disappearance on the west of the planet, at the moment of their immersion; but the view of their emersion will be intercepted by the body of the planet, and they will only reappear after having passed behind the planet.

The third and fourth satellites, after emerging from the shadow at c' . and appearing to be re-lighted, will again be extinguished when they come to the visual ray $E. J. a'$. which touches the planet. The moment of passing this ray is that of the commencement of their occultation by the planet. They will continue invisible until they arrive at the other tangential visual ray $E. J' b'$. when they will suddenly reappear to the east of the planet, the occultation ceasing.”

“In the cases of the first and second satellites, the commencement of the occultation preceding the termination of the eclipse, it is not perceived, the satellite at the moment of the interposition of the edge of the planet not having yet emerged from the shadow. In these cases, therefore, the disappearance of the satellite at the commencement of the eclipse, and its reappearance at the termination of the occultation, alone are perceived, the emersion from the shadow being concealed by the occultation, which has already commenced, and the disappearance at the commencement of the occultation being prevented by the eclipse not yet terminated.

When the satellite, proceeding in its orbit, arrives at

“ h' its shadow falls upon the planet, and is seen from the earth, at E , to move across its disc as a small black spot, while the planet moves from h' to h .

When the planet arrives at g . it passes the visual ray $E. J'$ and while it moves from g . to d . its disc is projected on that of the planet, and a transit takes place, as already described.

“Thus, at quadrature, the third and fourth satellites present successively all the phenomena of interposition: 1st, an eclipse of the satellite to the west of the planet shows both immersion and emersion; 2nd, an occultation of the satellite by the planet, the disappearance and reappearance being both manifested; 3rd, the eclipse of the planet by the satellite; and 4th, the transit of the satellite over the planet.”

(2957) “*Effects modified at other elongations.*—There is a certain limit, such as e , at which the emersion of the third and fourth satellites is intercepted, like that of the first, by the body of the planet. This is determined by the place of the earth from which the visual ray $e. J. c'$ is directed to the eastern edge of the section of the shadow at the planet's distance. Within this limit the phenomena for the third and fourth satellites are altogether similar, to those already explained in the case of the first and second satellites seen from E .

“When the earth is between s . and s' no eclipses can be witnessed. Those of the satellites are rendered invisible by the interposition of the planet, and those of the planet by the interposition of the satellites. When the earth is at e' and E' , the phenomena are similar to those manifested at e . and E ., but they are exhibited in a different order and direction. The occultation of the satellite precedes its eclipse, and the latter takes place to

“ the east of the planet. In like manner, the transit of the satellite precedes the eclipse of the planet.”

Examination of the Record.

In carefully examining the record of the phenomena together with the explanation contained in the foregoing, we particularly note the very positive assumption that “ these phenomena depend only on the motion of the satellites and the position of Jupiter’s shadow, and *have nothing to do with, and can have no dependence on the position or motion of the earth.*” On careful consideration it becomes evident that this assumption is made to apply not only to the actual phenomena but also to the apparent phenomena as viewed from the earth:— Is the assumption, so applied, wholly supported by the known circumstances belonging to the phenomena ?

If we first suppose the earth’s place to be at that part of its orbit nearest to Jupiter, and, having there noted the apparent magnitude (angular magnitude) of that planet, we then suppose the earth removed to the opposite extremity of the orbit to the place most distant from Jupiter, and again note the apparent magnitude of that planet, it is manifest that, the distance of the earth from the planet having increased by about 190 million miles, the apparent magnitude of the planet, as seen from the earth, must have decreased proportionally. Has this no particular relation to the phenomena, such as Lardner assumes that it has not ?

In the historical and descriptive statement of Roemer’s discovery just quoted, it is stated in effect (1) that Roemer’s computation of the times when the commencement of each eclipse was to be expected was made by

taking the time observed to elapse between two successive eclipses,* and multiplying that time by the number of eclipses included in the synodic period of the planet (Jupiter). (2) That as the earth receded from the planet, the actual commencement of the eclipse was later than the expected time given by the computation, and that this apparent retardation applied to each successive eclipse, so that the interval, by which the commencement of the eclipse was later, continually and regularly increased so long as the earth continued to recede from the planet. (3) That "as the earth again approached opposition, the difference became less and less, until, on arrival at *E.*, the place of opposition, the observed eclipse agreed in time exactly with the computation." †

Referring to the quotation from Herschel's *Outlines*, which will be found in the Appendix, we have the statement of that astronomer "when the earth comes to *F.*, a point determined by drawing *b.F.* to touch the body of the planet, the emersions will cease to be visible, and will thenceforth, up to the time of the opposition, happen *behind* the disc of the planet. Similarly,

* At the time of writing his historical statement of the discovery Lardner seems to have been under the impression that Rømer had computed his table from an observation taken when the earth was at or near to opposition, and that direct observation of the eclipses was then made, throughout the earth's revolution, from each successive part of its orbit. But, as shown elsewhere by Lardner himself, such a supposition is inadmissible because such direct observations throughout a great part of the earth's orbit are not possible. It appears likely that Rømer obtained his average time in the first instance by dividing the synodic period of the planet into the number of the eclipses within that period.

† Lardner's *Astronomy*.

Plate 6.

Fig. 5.

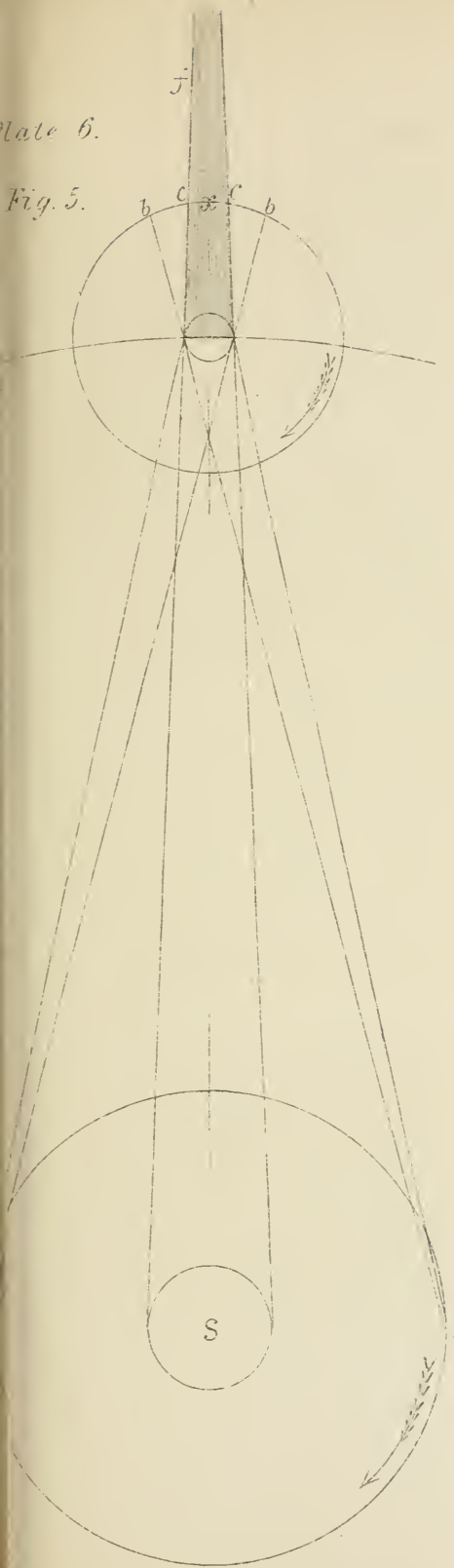
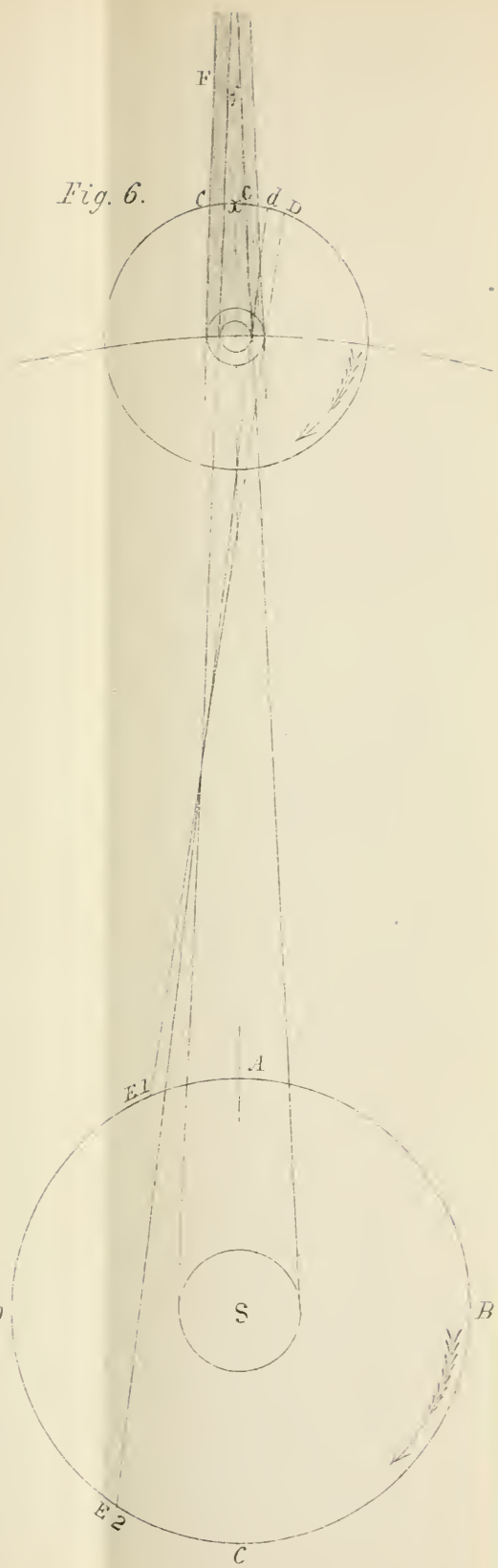


Fig. 6.



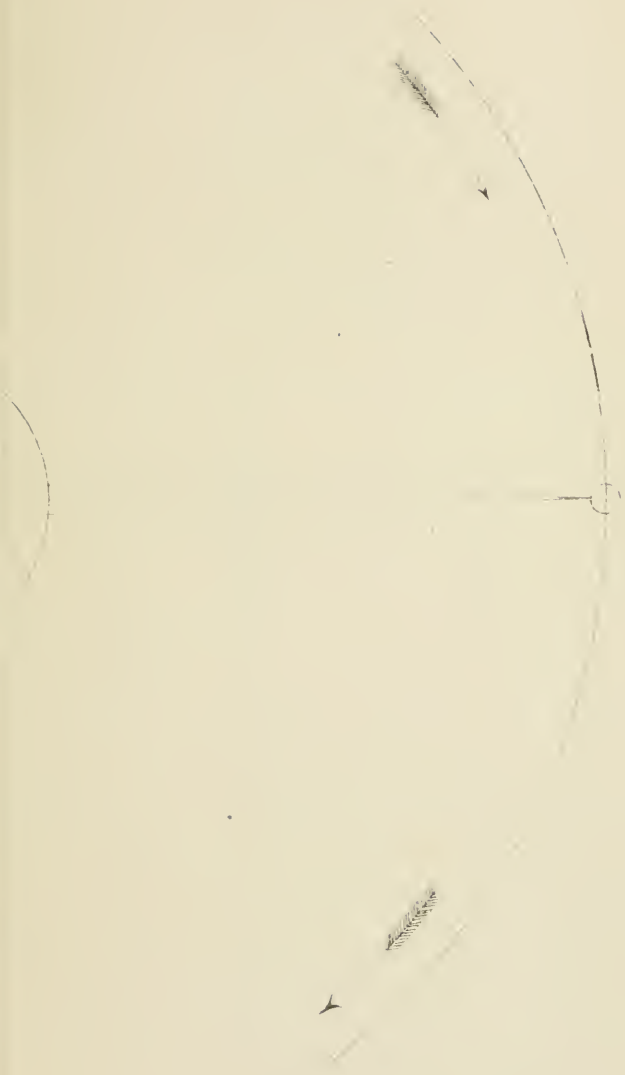
“from the opposition till the time when the earth arrives at *I*, a point determined by drawing a *I*. tangent to the eastern limb of Jupiter, the immersions will be concealed from our view.” And also, page 14, “It is to be observed that owing to the proximity of the orbits of the first and second satellite to the planet, both the *immersion* and *emersion* of either of them can never be observed in any single eclipse, the immersion being concealed by the body if the planet be past opposition, the emersion if not yet arrived at it, so also of the occultation. The commencement of the occultation, or the passage of the satellite behind the disc, takes place while obscured by the shadow before opposition and re-emergence after. All these particulars will be easily apparent on mere inspection of the Figure. (*See Appendix.*) It is only during the short time that the earth is in the arc *G.H.*, *i.e.*, between the Sun and Jupiter, that the cone of the shadow converging (while that of the visual rays diverges) behind the planet, permits their occultations to be completely observed both at ingress and egress, unobscured, the eclipses being then invisible.”

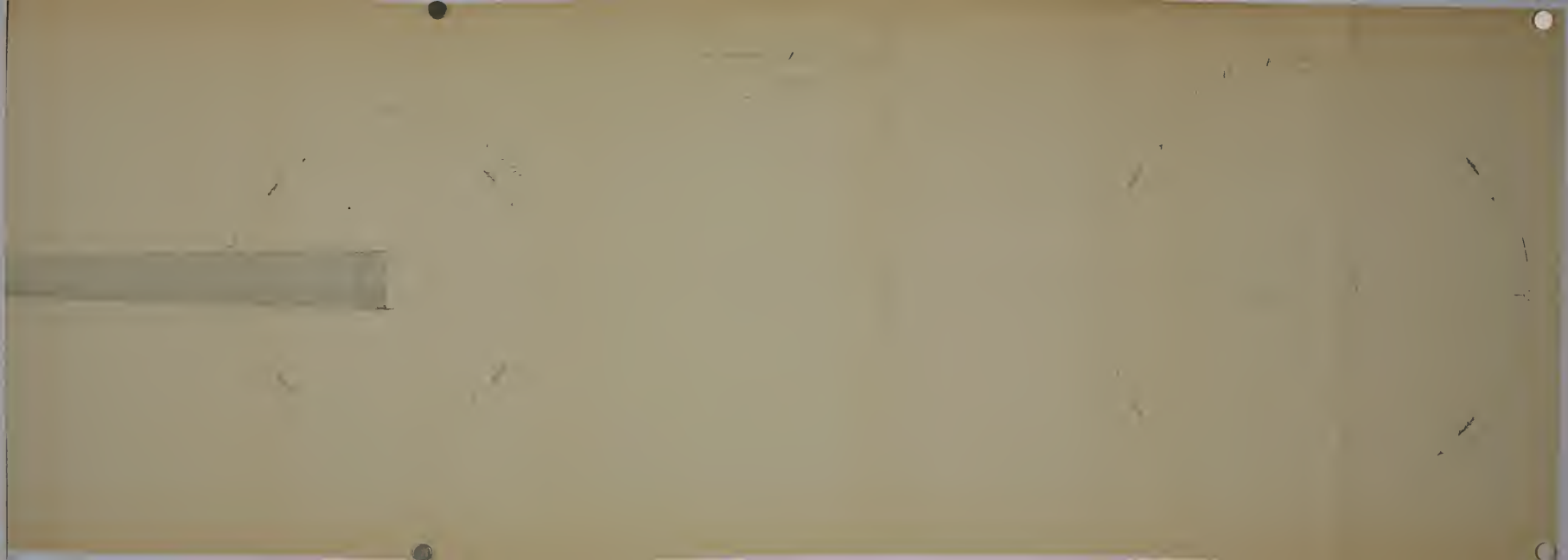
These statements are quite in agreement with those of Lardner himself in his general exposition of the phenomena belonging to Jupiter's shadow and satellites. (See quotation, page 32. “*All these phenomena manifested at quadrature ; &c., &c.*”)

It is therefore quite apparent that the circumstances set forth by Lardner, as the result of Roemer's investigation, in regard to the variation in time of the intervals between the successive eclipses, are not directly facts of astronomical observation, but are obtained by computa-

tion and inference from combined partial observations of the occultations and the eclipses. In the case of the two most distant satellites, when the earth is near quadrature—whether it be receding from or approaching the planet—the commencement and the termination of the eclipses are both visible independently of the occultations, but, with this exception, the times and circumstances of the eclipse are inferred from the commencement of the eclipse and termination of the occultation, or *vice-versá*. Now in regard to the variation in the apparent breadth of the planet's shadow as the earth approaches towards and recedes from it, it is quite true that no actual alteration takes place. The distance of the planet from the sun remains the same, and the distance of the satellite from the planet the same as before, and if the satellite's immersion and emersion into and out of the shadow could be directly observed, those observations would not be necessarily vitiated or affected by the apparent variation in the size of the planet's shadow: for all the parts and distances of the parts from each other, belonging to the Jovian system, including the planet itself and the planet's shadow, are similarly effected, and, increasing or decreasing in apparent size together, the relative proportions remain the same.

But in regard to the occultation...let us carefully examine whether it may be safely concluded that the approach and recession of the earth towards and from the planet does not cause any variation in the time during which the satellite is hidden from the terrestrial observer; or, to express in other words an equivalent





conclusion, whether this approach and recession does not cause any variation in the angular quantity of the satellite's orbital-arc cut off by the interposition of the planet: for if there be an arc sometimes of a greater and sometimes of a lesser angular magnitude, taken out of the orbital circle, there will evidently be a temporal variation caused in that part of the satellite's revolution which is visible.

Fig. 10 shows the planet, the orbit of the satellite, the planet's shadow, the sun, and the earth's orbit; the earth is shown at opposition and at conjunction; at those two places, therefore, in the orbit, at which the eclipse of the satellite is entirely hidden from view, and the occultation is completely visible, . . . that is, both the ingress and the egress of the satellite are visible.

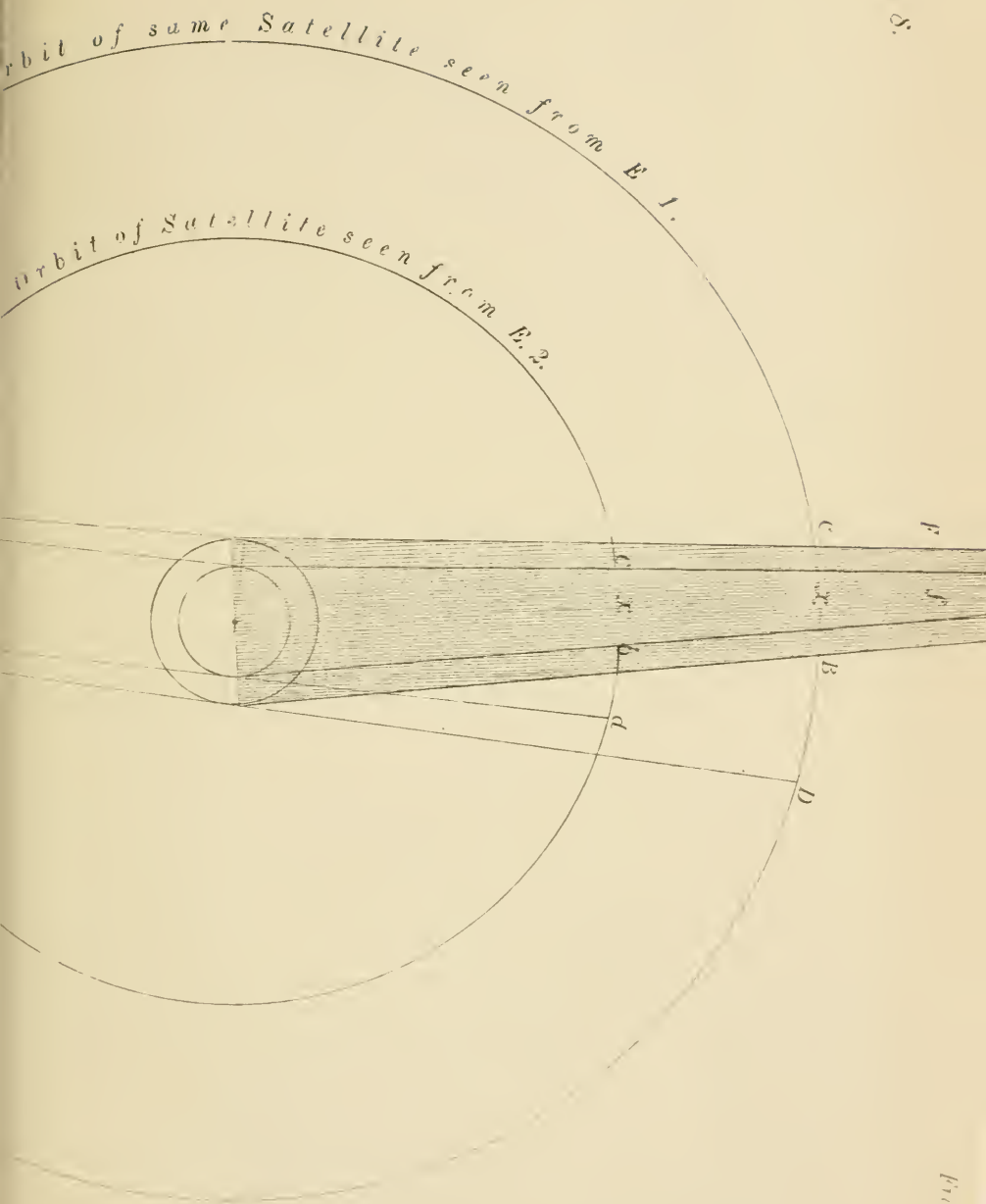
Now, by drawing the visual rays from the earth tangent to the disc of the planet. . . namely, from the earth at opposition and from the earth at conjunction, it becomes at once evident that there is a difference: for the arc *a. a.* of the satellite's orbital circle intercepted by the planet when the earth is least distant, at opposition, has, manifestly, a greater angular magnitude than the arc *b. b.* intercepted when the earth is most distant from the planet at conjunction. *Is this difference now recognized by astronomers?* Are those compound observations, which are in part direct in respect to the eclipse, and in part direct in respect to the occultation rectified relatively to this interfering circumstance? Roemer does not appear to have regarded it; Lardner does not mention it; in Herschel's treatise we do not find any reference to it what-

ever; nor have we met with any elsewhere. But the difference is a necessary consequence of the varying distance of the earth, and calls for consideration and satisfaction. It is a cause which must have its effect... how is that effect manifested?*

Let us go back to Roemer at the time of his first ascertaining the apparent variation in the interval between the successive eclipses...to that time when he has just conceived and is about to propose the theory of the velocity of light with the express purpose of accounting for an observed effect to which he can assign no adequate known cause. We now find a cause which must necessarily have its effect, to which no effect appears to have been hitherto assigned, and, moreover, a cause in kind and quantity precisely such as Roemer wanted to enable him to account for his observed effect.

What ground have we for retaining the theory or the velocity of light? It was notoriously suggested at first to supply a cause for a particular effect; and it was based upon that effect...but since it now appears that

* To sum up the evidence and concisely state the conclusion to which it has conducted us...we find that the so-called eclipses referred to by Roemer (and by those who are supposed to have verified his observations) were the obscurations of the planet caused by the occultations compounded with the eclipses (by the planet's shadow.) And that the fact observed by him of the increasing lateness in the commencement of the successive eclipses, as the earth receded to a greater distance from the planet, are due to the cause mentioned above and illustrated in fig. 10, viz: variation in the angle of occultation, subject to which the occultation or compounded eclipse was viewed, as the earth in its orbital revolution receded from and again advanced towards the planet.



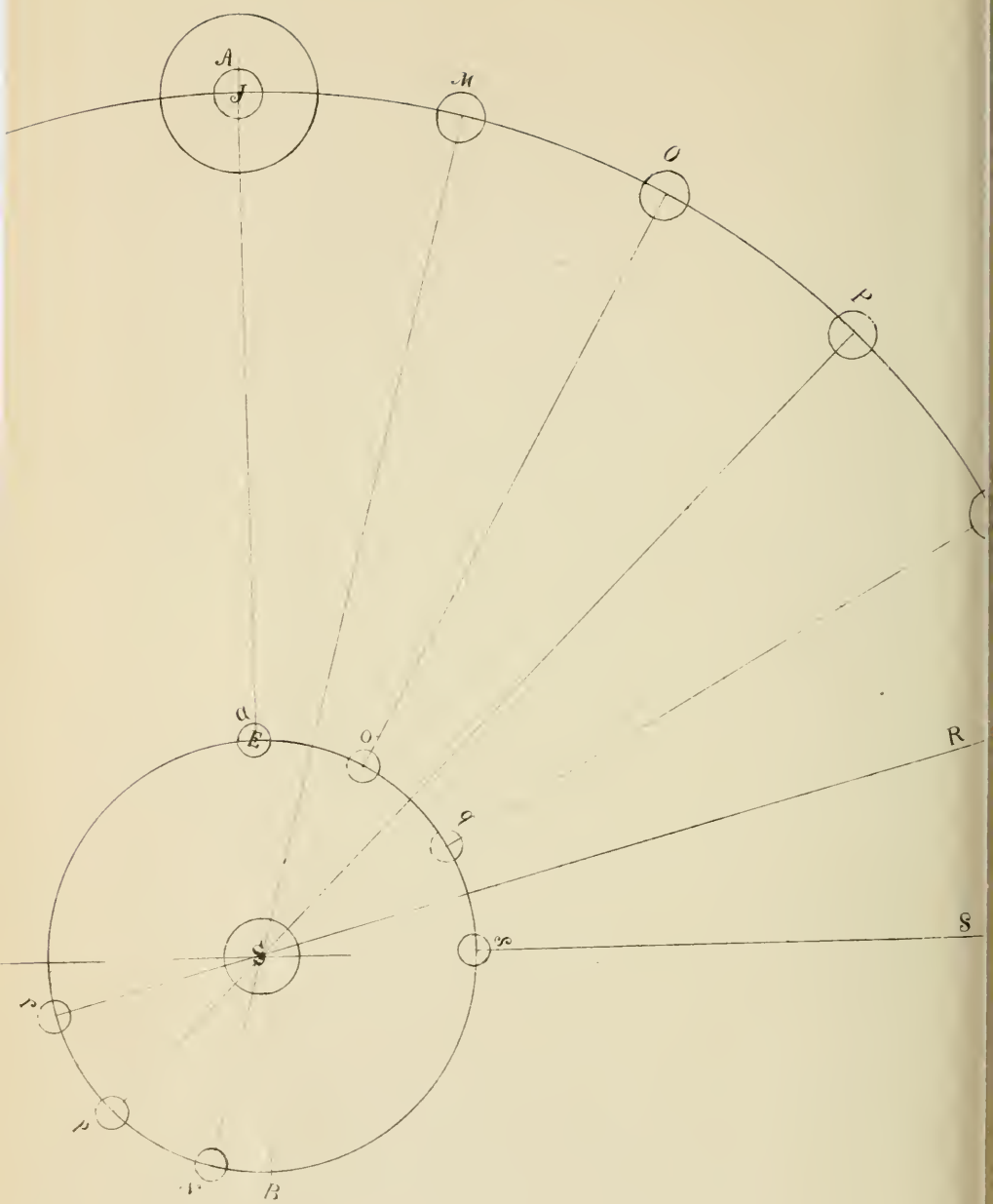
that particular effect is claimed by another cause which has a primary right to it...is there any other basis upon which the theory of the velocity of light may be supported? We opine there is none other, and that the theory must be pronounced untenable, because unsupported by fact.

Plate 5, Fig. 5 and 6, may serve as a general representation of the variation in the apparent scale on which the phenomena of the satellite's eclipse and occultation take place, according to whether it is viewed by the terrestrial observer from the earth's most distant or least distant place in its orbit. Fig. 8, which repeats a part of Fig. 6 on a larger scale, illustrates more especially the usual case of the eclipse compounded with the occultation. In this (Fig. 8.) it is evident that the angle subtended by the arc contained between the outer edge of the shadow on the one side, and the visual ray touching the side of the planet on the other, is greater when the progress of the satellite into the eclipse and out of the occultation, is viewed from the earth at its place of least distance, than when viewed from the more distant part of the earth's orbit.

A circumstance worthy of attentive consideration is that, from the statement of the observed facts in regard to the variation in the time of the eclipse as given by Lardner (and which we believe is quite a correct statement of the case as now accepted by astronomers), there does not appear to be any serious difficulty in the way of submitting Roemer's assumption to the direct test of astronomical observation: for—What is contained in that as-

sumption? That each revolution of the satellite when the earth is receding from the planet occupies a longer time than each revolution of the satellite when the earth is approaching the planet; and since the sum of the loss is 16 minutes, it follows that, if the number of revolutions made by the satellite in the Synodic period of the planet be m ., the difference in time of the satellite's revolution will be $32' \div m$, because when viewed from the one side of the orbit as the earth is receding, the time of the period is the average period of (the satellite) *increased by* $16' \div m$, and on the other side of the orbit as the earth approaches opposition the time of the period is the average period *less* $16' \div m$; the difference, therefore, is $32' \div m$. But this, again, is the average difference; and evidently at or near the earth's quadrature, when the recession or approach is more rapid, the difference would be greater. If we take the number of revolutions at about 190, the average difference in a single revolution, on the opposite sides of the orbit respectively, would be one-third of a minute, and if at or near quadrature, the difference would, perhaps, exceed half a minute.* Supposing, however, the difference on a single revolution of the satellite to be considerably less than this, it would still be a quantity of time which the practical astronomer can readily verify. This, then, is one of the distinct requisitions of Roemer's assumption which can be directly submitted to the decision of experience.

* If the earth receded (and approached) uniformly for equal increments of time, each revolution of the satellite during the recession (or approach), according to the assumption, would lose (or gain) an equal amount of time.



Let us now consider what effects would be necessarily consequent upon some very small quantity of time being occupied by light, in its communication from the sun to Jupiter, and from Jupiter to the earth. The quantity of *time* attributed by the theory (of the velocity of light) to a certain (definite) quantity of *motion*, seems to us less than reason authorizes the mind to accept as a (reasonable) possibility ; or, in other words, the velocity attributed to light, by that theory, seems to us greater than is scientifically conceivable, keeping in mind that, by the theory, this velocity represents the actual progressive motion of a variety or form of matter (*i. e.*, of a material substance). To simplify the consideration of the subject, however, we will assume, for the moment, the possibility of such velocity, and suppose it to be 8 minutes for a distance of 100 million miles. We will take Jupiter's distance roughly at 500 million miles, and thus we obtain at once a more distinct estimate of what the hypothesis involves. For instance ; in respect to the entrance of the satellite into the shadow of the planet, as described by Lardner, the assumption of the theory is that the satellite enters the shadow of the planet *in fact* about 40 minutes (on an average before it appears to us, viewing it from the earth, to do so ; and hence, the eclipse must be far advanced before it *appears to us* to have commenced.

Let us merely note here that this case is necessarily included in the assumption, and consider other consequents ; we will suppose the earth in its orbit, as shewn at *A. a.*, Fig. 9, (Plate 9) with the planet Jupiter in opposition, that is at the orbital place nearest to Jupiter.

The earth then travels round to the opposite extremity of the orbit, into conjunction of that planet. If the planet were to remain motionless, this place in the earth's orbit would be *B*, in the Fig. ; but, since Jupiter's angular velocity is about one-twelfth that of the earth, the planet will have moved through about 15° to *M*. ; and the earth's orbital place of superior conjunction will be *N*. For the earth again to arrive at the place of opposition of the planet, half the earth's solar orbit together with an additional 15° will be the distance required, and *O. o.* will be the place of opposition ; *M. O.* being equal to *A. M.*, and *a. o.* equal to twice *B. N.*, and in like manner *P. p.* will be the next place of conjunction, *O. P.* being also equal to *A. M.* So that the distance from opposition to conjunction is in fact equal to the distance from conjunction to opposition : but, on the assumption of the truth of the theory, will this actual equality in the distances also hold good when the motions are observed from the earth ? Taking the earth at *a.*, with the planet in opposition, and considering that, as the earth travels in its orbit towards *N.*, the distance of the earth from the planet continually becomes greater and, consequently, an increasing quantity of time is required for the light from the planet to reach the earth, we find that when the earth has arrived at *N.*, this apparent increase in the time actually occupied will, by the theory, amount to 16 minutes. But now, as the earth continues its progress and returns towards opposition, the contrary effect must take place, and the like apparent quantity of time be gained. The result must, therefore, be, if we compare the two halves

of the entire synodic revolution of the earth, a difference of 32 minutes. But, moreover, this semi-orbital difference, as measured by time, which belongs to the theory, is not peculiar to the planet Jupiter: it is equally applicable to any other superior planet, because the distance we are here considering is that of the diameter of the earth's orbit. Therefore we have to ask whether there can be a difference in time of about 32 minutes between the two halves of the synodic revolution in the case of each superior planet, which has never yet been observed, or which, in other words, has hitherto escaped the observation of all astronomers?

(*Note.*—It is undesirable in this place to complicate the subject by investigating the additional effect which would arise, under the hypothetical conditions of the case, in consequence of the reversed direction of the earth's orbital motion at opposition and at conjunction respectively. It will be sufficient to observe that, at opposition, light from the planet would, according to the theory, require about 36 minutes to reach the earth which would be then moving from east to west; and at conjunction, about 52 minutes, when the earth would be moving from west to east.)

But let us consider the case of an inferior planet; take, for example, the planet Venus. Now, there is this difference between the case of an inferior and that of a superior planet; that, when the former is in inferior conjunction the solar light passes the planet and comes directly to the earth. When, however, the inferior planet is in superior conjunction, the case is similar to that of the superior planet, and the light of the sun going first to the planet is reflected therefrom to the earth.

Herein we observe another favourable opportunity to submit the fundamental assumption of the velocity-of-light theory to the test of fact; for, the transit of Venus furnishes the moment of inferior conjunction almost independently of the velocity hypothesis,* the solar light at that time having a distance of only about 26 million miles to reach the earth, which distance by the theory, would require a little more than 2 minutes; whereas, at superior conjunction the distance of Venus from the earth is about 165 million miles, requiring by the theory about 14 minutes; a difference in time therefore of about 12 minutes. Let us therefore ask the practical astronomer for a decided answer *on fact* as to whether the planet Venus takes 24 minutes longer to travel from inferior to superior conjunction than it takes to travel from superior to inferior conjunction.... For it is a requisition of Roemer's assumption that there shall be such difference, and if astronomical observation shows that there is no such difference..then fact is against the assumption.

* Because the supporters of the theory expressly reject the testimony of sight as evidencing that what *appears* to take place at a certain time *does actually* take place at the time. We are told. . .No: your sight deceives you; you are reading only the record of the past; what appears to you to be now taking place has in *fact* taken place some time since.

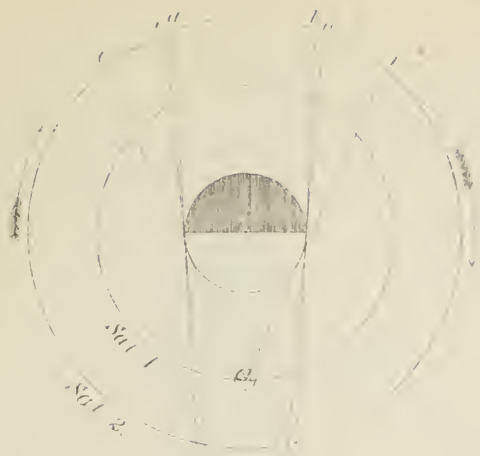
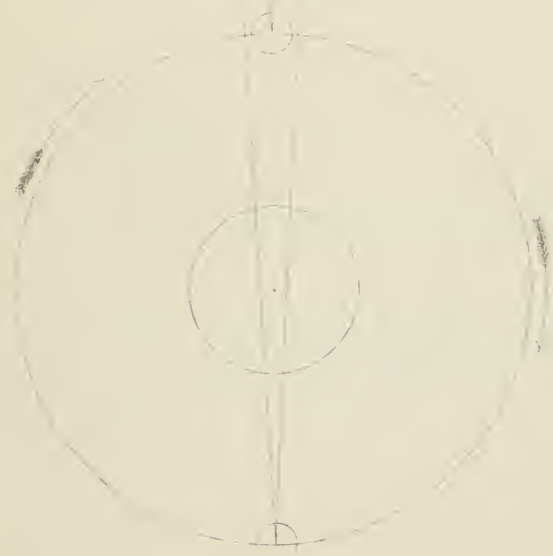
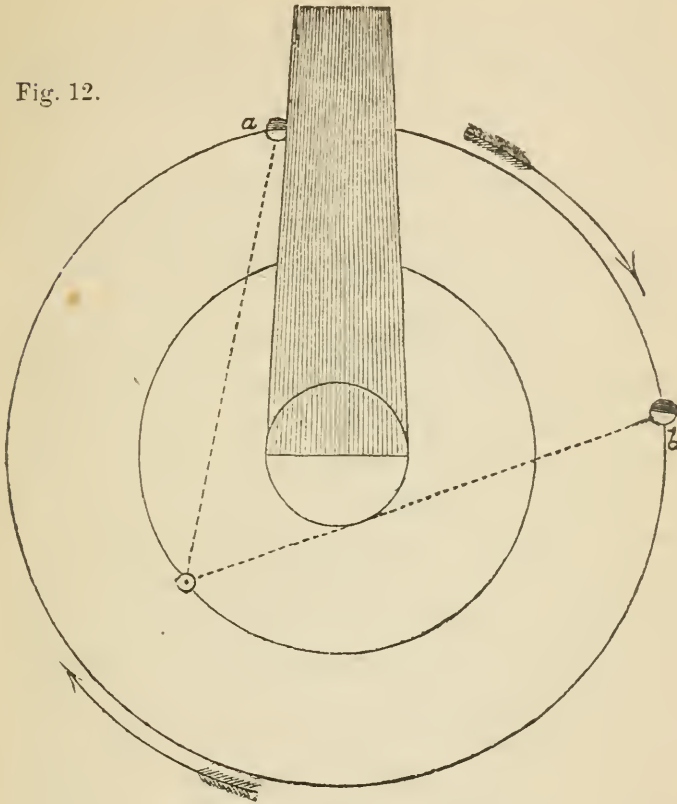


Fig 11.



The combined eclipse and occultation of Jupiter's second satellite viewed from the first satellite; supposing the latter (the first satellite) to remain stationary.

Fig. 12.



The second satellite is seen entering the western side of the shadow at *a*, and is again seen emerging from behind the eastern limb of the planet at *b*.

Fig. 11—Supposes occultation of the second satellite to be viewed from the first, which is supposed to remain stationary at conjunction (between the centre of the planet and the sun).

LIGHT.

We have now examined, carefully and attentively, those two comprehensive theories of light which have successively received the approval and concurrence of men of science.

Of the two theories of *the nature of light*, Newton's corpuscular or emission theory, which is the oldest and most definite of them, has been given up and discarded in favour of the undulatory theory.

These two theories, although, in many respects, differing widely from each other, are both founded on an assumption that light is in its nature material. . . . that it is either a variety or peculiar description of matter, or else, a dynamical manifestation of matter. By the one theory, a particle of the peculiar matter leaving the luminiferous body by which it is emitted, travels onward in a right line until it comes in contact with the recipient, and the impact of the material particle upon the material body produces the effect termed light. By the other theory a material fluid is supposed, and the effect is conveyed and communicated by means of the material particles of this fluid: a wave, vibration, or impulse, commencing at the luminiferous body, is propagated through and by means of the material particles of the fluid ether, and, again, there is impact, by matter in motion upon the material body of the recipient, occasioning the effect termed light. By either theory, therefore, time is necessarily occupied in the communication of the

light from the emittent or luminiferous body to the recipient. . the particles, or the vibrations leave the emittent body, they move through successive spaces, and they arrive at the place of the recipient. Both theories, therefore, belong in common to a primary velocity-of-light hypothesis or theory, and it is as to the reality of the basis, upon which this fundamental hypothesis is supposed to rest and upon which the entire superstructure is supported, that the concluding part of our investigation has been directed.

The supposed facts (of observation) upon which the velocity-of-light hypothesis is based, and upon which it is primarily altogether dependent, are three. Of these, the oldest and by far the most important (and which is, indeed, generally looked upon as being alone the fundamental and sure support of the theory), is Roemer's observations of the eclipses of Jupiter's satellities. We have now shown, with respect to those observations, that the velocity-of-light assumption, adopted to explain the variation in the apparent period of the satellites, is a mistake which has arisen in the omission to appreciate the variation in the occultation-angle occasioned by the increase and decrease of the earth's distance from the planet.

The second of the supposed facts is the so-called *aberration of light*. It has been now shown that the reasoning which attributes certain natural phenomena to such suppositious cause is unsound, and that the aberration theory is merely notional without actual support of fact. It is therefore unreal.

The third supposed fact is the result of certain experiments with Wheatstone's reflecting apparatus. But the result of these experiments as evidence on the primary question, *viz.*, whether light has velocity, was assumed therein; and the actual question which the enquirer proposed thus to submit to experiment, to be answered and determined, was—what is the quantity or amount of the velocity?*

If it be assumed, on the contrary, that light has no velocity, an experiment with an apparatus of this description similarly conducted would, nevertheless, give an apparent velocity as the result, according to the number of reflectors employed; because the light leaves the last reflector subsequently to its leaving the reflector next before it, and, again, it leaves that one subsequently to the one next before that, and so on; and, therefore, in a series of reflectors, a certain time would be occupied in the transmission of the light from one reflector to the next.†

*That is to say, time would be occupied in the act of reflection, not in the communication of the light from the surface of the one reflector to the surface of the next.

†In thus stating the question, submitted to experiment, we are according to our view, extending rather than lessening the significance of the question actually submitted. The question submitted was practically . . . Is that amount of velocity already established exactly correct? The conviction (prejudice) in the minds of those submitting the question being not only that a velocity was established, but that the quantity of velocity had been ascertained either with precision or with a close approximation thereto. In all probability more than a slight discrepancy in the result, from what it was already decided that result must be, would have condemned the apparatus as being in some way unsuitable for the experiment.

It is true the result of the experiments with this apparatus is stated to have been in close agreement with the velocity which had been previously attributed to light ; but, when we consider that such an agreement, even if the experiments were conducted with scrupulous precaution and care, might be quite fortuitous, and when we consider, also, that the experiments were undertaken with a foregone conclusion or prejudice of so strong a character that it might be called a conviction, (*i. e.*, an unsound conviction,) not only as to a velocity but also as to the established quantity of that velocity, we cannot allow that these experiments, *viz.*, with Wheatstone's reflecting apparatus, standing alone and unsupported, which they now do, are entitled to be considered as furnishing evidence of value in any degree in regard to the primary question.

Since, therefore, it has been now shown that the several theories, which attribute a material nature to light (meaning thereby the influence which occasions light), are each of them seerally, and all of them collectively, unsound and consequently untenable ; and since it has been also shown that the supposed facts of observation, by which the velocity attributed to light was considered to be established, are, in that sense, illusory, and do not, in fact, support such conclusion, we are thrown back upon the primary question. . . . *is light material ?* Now if light be *material* in its nature, it is certain that *time* must be occupied in its transmission ; and, inverting the proposition, if no *time* is occupied in its transmission, then it is certain that light is not of a *material* nature. To answer

the question in this form we have the positive evidence of Roemer's observations, confirmed by all later observers, of the eclipses of Jupiter's satellites. This is, perhaps, the only positive (direct) evidence* which can, at the present moment be put before the reader as fact demonstrated by direct observation, and as, therefore, indisputable: but it is, we opine, entitled in itself to be considered conclusive; for the distance of the planet Jupiter is so great that, as already stated, any conceivable velocity of a material substance or of an influence transmitted by means of a material fluid (or any description of matter) would necessarily occupy a very appreciable quantity of time in travelling from that planet to the earth: consequently, since it is established by astronomical observation that no appreciable quantity of time is occupied in the transmission from the planet Jupiter, the evidence is positive and decisive that light has no velocity. Wherefore we conclude that the evidence *in fact* is sufficient to answer demonstratively the primary question; and the answer to that question is accordingly—that the nature of light (meaning thereby the influence which occasions light) is spiritual, and not material.

Assuming that the conclusion just stated, in regard to

* There is much *negative* evidence, some of which we have alluded to, or indicated. Theoretical considerations are, we opine, in the present state of knowledge, if the mind be freed from the prejudice occasioned by the undulatory and other theories, altogether opposed to the idea of light having velocity. If, for example, such a supposition be entertained, it immediately appears to follow that interference and confusion, occasioned by light arriving at the same time from a number of different objects, would necessarily take place.

the primary question, is sound; let us now see what secondary conclusions of an important character will follow as corollaries or consequents thereto.

For this purpose it will be convenient to take Physical Science, or that division of Physical Science to which the phenomena of light and sound belong, and to put these conclusions in the form of a brief generalization, making use of certain of the recorded facts, and a part of that common knowledge belonging to the subject, which may be considered certified by Science at the present time.

THE PHYSICAL FORCES OF NATURAL SCIENCE.

Force is that which causes a change in the condition of matter, overcoming a resistance (antagonism or opposition); which *resistance* is equal in amount to the *quantity* of force exerted.

Force is known to us as manifested in several forms or conditions (modes), differing from each other and having its active energy in each condition controlled by definite and distinct laws, which, having been more or less investigated, are now in some measure known.

The several forms or modes of force, now recognized as acting on the material world, and distinguished each from each by the effects on matter of its manifestations, definite and different in the one particular form from those in each of the other forms, are. . . .

	<u>Forms of Force.</u>	<u>Manifestations of Force on Molecular Matter.</u>
{	Electric Force.	{ Volumetric Electricity. Light.
	Magnetic Force.	{ Heat. Molecular (Voltaic) Electricity.
	Acoustic Force.	{ Sound.
		<u>Manifestations of Force on Aggregated Matter.</u>
{	Dynamic Force.	{ Motion of Material bodies. Mechanical effect.
	Gravitative Force.	{ Mechanical effect. Weight or Gravity.

All *change* in the material world is the result of a *manifestation* of *force*. The primary or general law under which all the forms or conditions (modes) of force are manifested and become cognizable by us is that of *succession*.

The *successive manifestations* of *force*, that is, its measurement by the successive effects of its manifestations on matter is known to us as *time*. *

Distance is the quantity of separation (*i.e.*, intervening space) between definite localities at which manifestations of force upon matter are cognized.

Force is, therefore, not *material* but *spiritual*. Since the cognition of the material world (*i.e.*, of matter) by the spiritual being, is in ourselves a manifestation or result of *force-energy* acting on *matter*, we cannot divest ourselves of the *idea* of *time* in cognizing matter except in the case of a *simple sensation*, because the successive recognitions of the successive effects is that which we mean by the expression 'idea of time.'

But *matter* itself, in its simple elementary condition, separated from force, is only indirectly known to us. Chemical science teaches us to indirectly recognize the fact that such simple elementary matter is existent †, but

* This may be familiarly illustrated by reference to the dial-plate of a clock, where the motion of the hour-hand measures the successive vibrations of the pendulum. The measurement may be read off (cognized) in hours, minutes, or seconds, but it is always a measurement from a definite starting point (zero-point), and it expresses the collective cognition of the successive vibrations which have taken place subsequent to that point.

† *But to assume that* chemical evidence, as set forth in the atomic theory, makes us acquainted with simple elementary matter separated from *force* is, perhaps, to assume (*i.e.*, to include the assumption) that matter itself is primarily a materialized (fixed) condition or mode of (gravitative) force.

it has not been, neither can it be, directly cognized by us apart from its spiritual adjunct *force*.

Therefore all the forms or varieties of compound matter known to us, are compounded of (*the spiritual and the material*) force and matter.

And, also, by an addition to or a deduction from the quantity of *force* contained in a particular form (variety) of matter, the physical condition of that form of (compounded) matter may undergo a change..although its essential form as distinguished from other forms of (compounded) matter remains unaltered. . . .as, for example water, which by the addition or deduction of that form of force known as *heat*, assumes accordingly the condition of *steam* or of *ice*, in either of which conditions it still remains essentially the same form or variety of (compounded)matter—viz., *water*, as distinguished from all other varieties of matter.

Force in combination with matter may be considered dormant or *latent* ; the energy of the force may be said to be employed (in resisting change) in preserving the existence, condition, and form of the compounded matter ; it has been (so to speak) *materialized*, and has become (temporarily) a part of the compound matter ; but, if the equilibrium of the compounding elements of the body be disturbed by addition or interference of (other) *force*, the condition, or, it may be, the compounded form, of the body must undergo modification or decomposition, and a certain quantity of force, exactly proportional to the quantity of matter acted upon and changed, is set free to manifest its energy as active force, by combining

with or disturbing the conditions of, other forms of compounded matter.

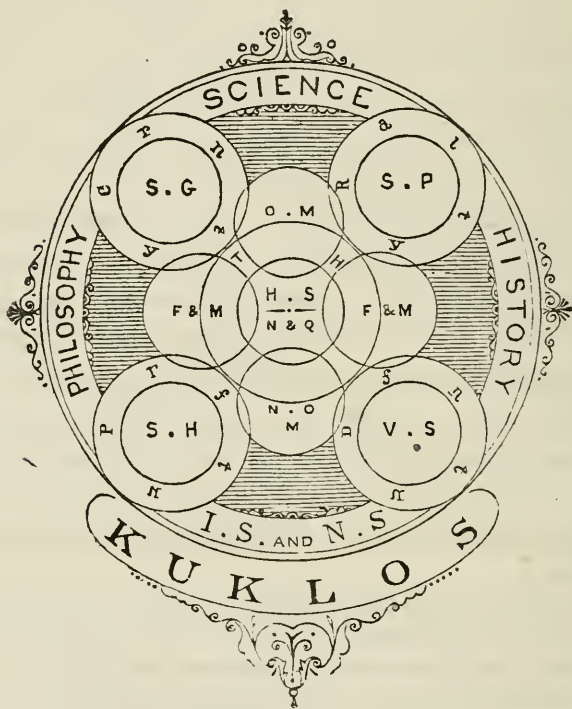
Herein we have particular sources of *force* or of manifestations of force-energy within the material world, as known to us. It may be said that the source of all the force-energy usually recognized as belonging to the material world is such a disturbance of existing compounds or combinations, and the consequent setting free of force previously latent or inactive, in the compound. Sidereal (solar) force may be, however, considered as, to some extent, a possible exception* *i.e.*, as, possibly, including an outside source; because, although there is strong probability that the active or free force thence derived is the result only of a continuous regulated (material, disturbance of the same character, and that the sun may be correctly understood to act as a reservoir of force, continually collecting and redistributing a regulated supply—nevertheless we cannot be quite sure, in the present state of knowledge, that sidereal (solar) force may not include a more distinct manifestation of outside † spiritual energy, in which case solar force would have to be looked upon as the primary ‡

* If it be assumed that the aggregate quantity of compound matter in the universe undergoes increase, *i.e.*, that a manifestation of Creative energy is continually or occasionally taking place, a proportionate addition to the collective quantity of force would be, perhaps, necessary, and (it is meant that) the sun, or other central star, may possibly be the medium through which such additional quantity is supplied.

† Meaning thereby . . . a source outside that which is known to us as the material universe.

‡ That is—primary, in a merely terrestrial sense.

source of terrestrial force; whereas, otherwise, *i.e.*, assuming the sun to be simply the central recipient and distributor of active force—all terrestrial (or planetary) and solar manifestations of force must be looked upon equally as parts of that collective quantity of force belonging to the solar system.



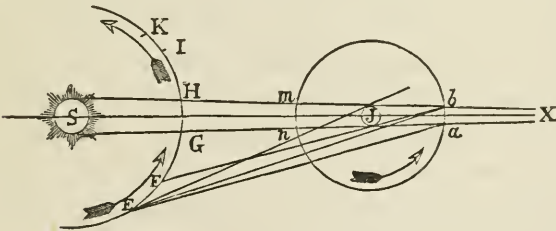
APPENDIX.

(1.) ECLIPSES AND OCCULTATIONS OF JUPITER'S SATELLITES.

Herschel's Outlines of Astronomy.

(537.) "These eclipses (of Jupiter's satellite's) moreover, are not seen, as is the case with those of the moon, from the centre of their motion, but from a remote station, and one whose situation with respect to the line of shadow is variable. This, of course, makes no difference in the *times* of the eclipses, but a very great one in their visibility, and in their apparent situations with respect to the planet at the moments of their entering and quitting the shadow."

(538) "Suppose *S.* to be the sun, *E.* the earth in its orbit, *E. F. G. K., J.* Jupiter, and *a.b.* the orbit of one of its satellites. The cone of the shadow, then, will have its vertex at *X*, a point far beyond the orbits of all the satellites; and the penumbra, owing to the great distance of the



sun, and the consequent smallness of the angle (about $6'$ only) its disc subtends at Jupiter, will hardly extend, within the limits of the satellites' orbits, to any perceptible distance beyond the shadow—for which reason it is not represented in the figure. A satellite revolving from west to east (in the direction of the arrows) will be eclipsed when

“it enters the shadow at *a.*, but not suddenly, because, like the moon, it has a considerable diameter seen from the planet; so that the time elapsing from the first perceptible loss of light to its total extinction will be that which it occupies in describing about Jupiter an angle equal to its apparent diameter as seen from the centre of the planet, or rather, somewhat more, by reason of the penumbra; and the same remark applies to its emergence at *b.* Now, owing to the difference of telescopes and of eyes, it is not possible to assign the *precise* moment of incipient obscuration, or of total extinction at *a.*, or that of the first glimpse of light falling on the satellite at *b.*, or the complete recovery of its light. The observation of an eclipse, then, in which only the immersion, or only the emersion, is seen, is incomplete, and inadequate to afford any precise information, theoretical or practical. But, if both the immersion and emersion can be observed with *the same telescope* and *by the same person* the interval of the times will give the duration, and their mean the exact middle of the eclipse, when the satellite is in the line *S.J.X.*, *i.e.*, the true moment of its opposition to the sun. Such observations, and such only, are of use for determining the periods and other particulars of the motions of the satellites, and for the calculation of terrestrial longitudes. The intervals of the eclipse, it will be observed, give the synodic periods* of the satellites' revolution; from which their sidereal periods must be concluded by the method in art. 418.”

(539) “It is evident, from a mere inspection of our figure, that the eclipses take place to the west of the planet, when the earth is situated to the west of the line

* This statement is noteworthy. The inference may be supposed to apply also to the intervals between the commencements of the successive occultations. In either case it is only hypothetically true...on an assumption that the earth remains stationary; for if the earth move to another place in its orbit there must be parallax and alteration in the visual angle.

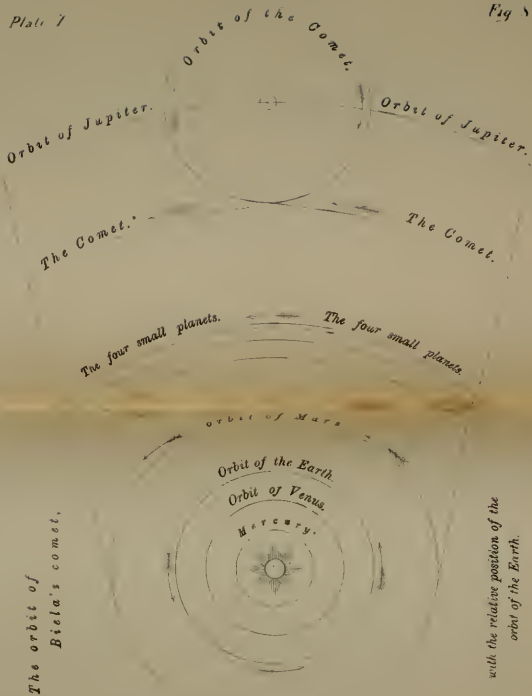
S.J., i.e., before the opposition of Jupiter; and to the east, when in the other half of its orbit, or after the opposition. When the earth approaches the opposition, the visual line becomes more and more nearly coincident with the direction of the shadow, and the apparent place where the eclipses happen will be continually nearer and nearer to the body of the planet. When the earth comes to *F.*, a point determined by drawing *b.F.* to touch the body of the planet, the *emersions* will cease to be visible, and will thenceforth, up to the time of the opposition, happen *behind* the disc of the planet. Similarly, from the opposition till the time when the earth arrives at *I.*, a point determined by drawing *a. I.* tangent to the eastern limb of Jupiter, the *emersions* will be concealed from our view. When the earth arrives at *G.*, [or *H.*] the immersion [or emersion] will happen at the very edge of the visible disc, and when between *G.* and *H.* [a very small space] the satellites will *pass uneclipsed behind the limb* of the planet."

(540) "Both the satellites and their shadows are frequently observed to *transit* or pass across the disc of the planet. When a satellite comes to *m.*, its shadow will be thrown on Jupiter, and will appear to move across it as a black spot till the satellite comes to *n.* But the satellite itself will not appear to enter on the disc till it comes up to the line drawn from *E.* to the eastern edge of the disc, and will not leave it till it attains a similar line drawn to the western edge. It appears then that the shadow will *precede* the satellite in its progress over the disc *before* the opposition of Jupiter, and *vice versa.*"

(541) "Besides the eclipses and the transits of the satellites across the disc, they may also disappear to us when not eclipsed, by passing behind the body of the planet. Thus, when the earth is at *E.*, the immersion of the satellite will be seen at *a.*, and its emersion at *b.* both to the west

“of the planet, after which the satellite, still continuing its course in the direction *b*., will pass behind the body and again emerge on the opposite side, after an interval of occultation greater or less according to the distance of the satellite. This interval, (on account of the great distance of the earth compared with the radii of the orbits of the satellites,) varies but little in the case of each satellite, being nearly equal to the time which the satellite requires to describe an arc of its orbit, equal to the angular diameter of **Jupiter** as seen from its centre, which time, for the several satellites, is as follows: viz., for the first, 2h. 20m.; for the second, 2h. 56m.; for the third, 3h. 43m.; and for the fourth, 4h. 56m.; the corresponding diameter of the planet as seen from these respective satellites being $19^{\circ} 49'$; $12^{\circ} 25'$; $7^{\circ} 47'$; and $4^{\circ} 25'$. Before the opposition of Jupiter, these occultations of the satellites happen *after* the eclipses: after the opposition when, for instance, the earth is in the situation *K*., the occultations take place before the eclipses. It is to be observed, that, owing to the proximity of the orbits of the first and second satellites to the planet, *both* the immersion and emersion of either of them can never be observed in any single eclipse, the immersion being concealed by the body, if the planet be past its opposition, the emersion, if not yet arrived at it. So also of the occultation. The commencement of the occultation, or the passage of the satellite behind the disc, takes place while obscured by the shadow, before opposition, and its re-emergence after. All these particulars will be easily apparent on mere inspection of the Figure, Art. 536. It is only during the short time that the earth is in the arc *G. H.*, *i. e.* between the sun and Jupiter, that the cone of the shadow converging (while that of the visual rays diverges) behind the planet, permits their occultations to be completely observed both at ingress and egress, unobscured, the eclipses being then invisible.”

LECTURE FOURTH.



The period (solar period) of the comet is 900 days (nearly $2\frac{1}{2}$ years)

The terrestrial period is at present reckoned, according to the theory of cometary orbits, at 2,610 days. This we consider, according to the law of gravitation, represents 3 orbital returns of the comet. Wherefore 2,610, divided by 3, equals 803 $\frac{1}{3}$. But the comet requires 145 days to complete the seventh (annual) orbit, and taking the velocity of the comet at one-half that of the earth, $2,610 \div 200 = 13050$. And 2700, divided by 3, equals 900 days, which is, therefore, the solar period.

See page No 125

COMETARY ORBITS

IN RELATION TO

THE LAW OF GRAVITATION

BY

JOHN HARRIS.



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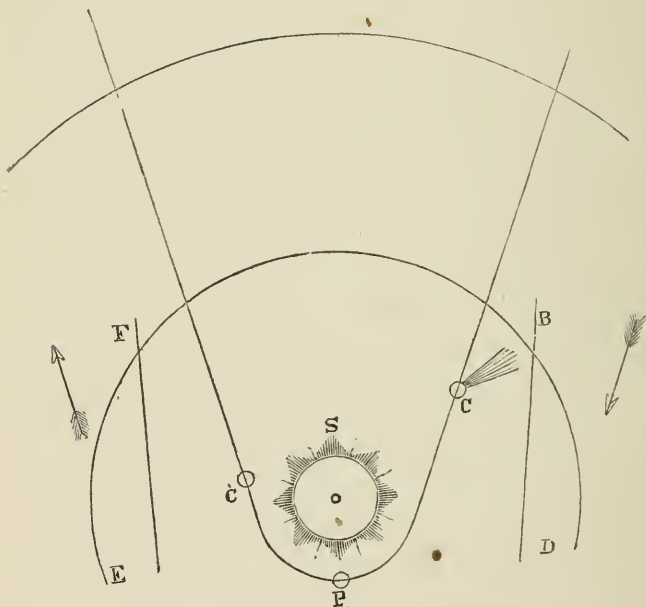
LECTURE FOURTH.

MASSES OF AGGREGATED MATTER AND THEIR RELATION TO THE LAWS OF THE MATERIAL UNIVERSE.

The assumption that masses of matter, revolving around centres of gravitating influence in the neighbourhood of, but not belonging to, the solar system, may approach sufficiently near to be visible from the earth, will perhaps enable us to understand and give a reasonable explanation of some of those observed facts of astronomy, which at present occupy the position of mechanical effects apparently governed and regulated by laws unknown to or unrecognized by mechanical science. We allude more particularly to those very various bodies at present grouped and classed together under the name *comet*. Plate 16, from the (*Encyc. Britannica*), is an example of the illustrations given at the present time in astronomical works, of the supposed orbital revolution of a comet around the sun. In some cases the orbital path is considered to be an ellipse of extreme eccentricity; in other cases, a parabola; or, a hyperbola. The objection to this teaching seems to have been overlooked that it is inadmissible in a scientific sense, because contrary to the law of gravitation; a law which is recognized both by astronomical and mechanical science. In Fig. 2, the body C, to the north-east of the sun, is moving with an increasing velocity in the direction BD. The gravitating influence of the sun is supposed, at this part of the comet's orbit, to exceed

the centrifugal force, causing it to gravitate towards and approach the sun. Since the approach is very considerable in extent and rapid, so is the increase in the velocity proportionately great, and when the comet has arrived (*i. e.*, supposed to have arrived) at its perihelion P, it is moving with enormous velocity past the sun in the direction DE ; for a certain short distance, it proceeds in a curve not differing very much from the arc of a circle, but then, notwithstanding that it is supposed to be comparatively

Fig. 2.



very near the sun and under the influence of an enormous attractive force, it suddenly ceases altogether to obey this force, and proceeds in the direction EF, as shown in the figure, without any further regard to the

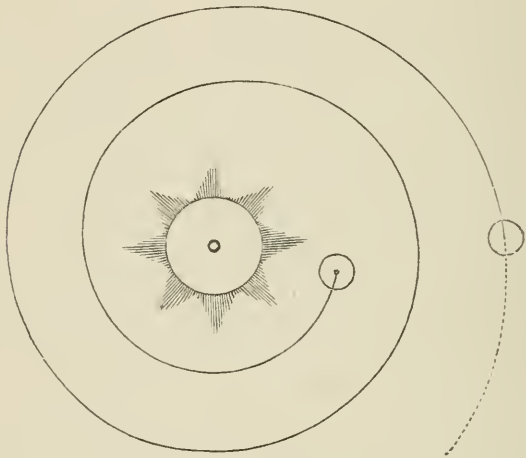
central gravitating influence. If the body is material and subject to the known laws governing matter when moving from B towards D, and if, even after passing its perihelion, it still retains its material nature and recognizes the influence of gravitation until beyond E, how is it to be admitted that its subjection to the laws of matter can be suddenly abrogated? We cannot admit a supposition that any material mass, having once become subject to the sun as the central gravitating influence governing its motion, and thus belonging to the solar system, can suddenly throw off its allegiance and withdraw from the sun's controlling power into space, or to visit some other system in a similarly capricious manner. If we assume the body (comet) to have arrived at the place (P) shown in the figure, nearest the sun, (without troubling ourselves to explain how it got there), and to be moving past the sun with such very great velocity that the centrifugal force developed is more than sufficient to counterbalance the enormous attractive force of the sun, at so short a distance; then the inference will be sound that the comet must recede from the sun; and further, the distance to which the comet will recede will be proportional to the excess in the centrifugal force over the gravitative force when nearest to the sun, as explained and demonstrated in Part First of this Series;* but even in such case the recession could only take place in an orbit with a continually increasing radial distance from the sun, as shown in Fig. 3, and the path of the receding body would have the form of a spiral curve continually increasing outwards from the sun as its centre.

(1) *The Compound Siderial Orbit.*—As already stated, it is not permissible to entertain the supposition that a

* The series on physical science entitled 'Centrifugal Force & Gravitation.

planet or other mass of aggregated matters, revolving around the sun (or other centre) under the influence of gravitation, can suddenly divest itself of that influence, consequently the hypothesis which supposes the orbital path of a comet to describe a parabola or a hyperbola must certainly be erroneous. It is, nevertheless, quite possible for a planetary or cometary mass of matter to enter the solar system, and, being within the sun's

Fig. 3.



gravitating influence, to approach the sun, and even to make a partial revolution about the sun, and then to depart or return to another system.

To explain this more particularly we refer to Fig. 1, (Pl. 1.) where *A.* represents the sun, and *B.* represents the central *star* of a neighbouring system; *C.* a comet or cometary mass of matter; *m. y. n. p. q. v.* the comet's supposed orbit. From the place *m.*, the comet moves in the direction of the arrows through the circular arc *m. c. n.*, having *B.*, the *star*, for the centre of gravitation; having arrived at the point *n.*, the direction of motion is the tangent to the arc: viz., *n. o.* Now if *C.*, the comet were

Fig. 4.

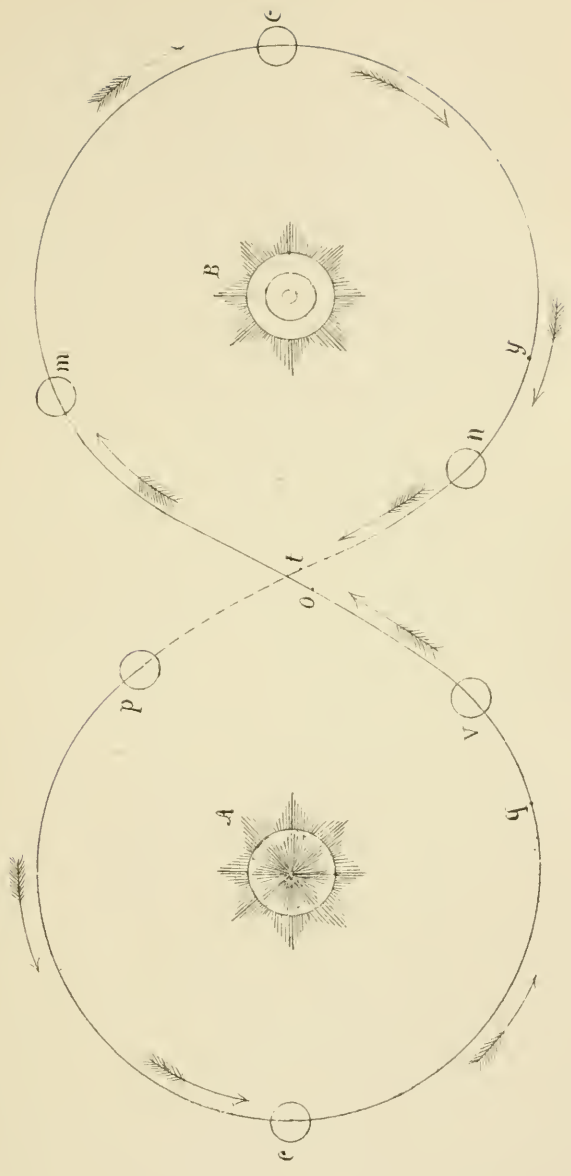


Plate. 1.

strictly a member of the system belonging to *B.*, and confined to that system, that is to say, beyond the influence of any other gravitating centre, then, the influence of *B.*, being counteracted only by the centrifugal force of the moving comet, would restrain it from deviating out of the circular path, but the distance of the comet *C.* from *B.*, is so great that, when it has arrived at *n.*, the influence of the sun *A.*, has already begun to act upon it, and by counteracting the influence of *B.*, lessens the effect of the latter; consequently the motion of *C.* deviates outside the circle and towards the tangent; so that the orbital path *n. t.* is intermediate between the arc of the circle and the tangent. At this point, being at about the half distance between *A.* and *B.*, their opposing influences are about equal, and *C.*, therefore, moves in the direction of the tangent. The comet is now rapidly receding from *B.*, and approaching *A.*; when it has arrived at the place *p.*, the comparatively feeble influence of *B.* will be effective only in retarding the motion and diminishing the velocity, which will have just previously increased in consequence of *A.*'s influence during the approach of the comet towards *A.*, whilst moving from *n.* to *p.* After passing the place *p.*, the influence of *A.* will be alone effective in restraining and governing the motion of the comet, which will therefore move in a circular orbit round *A.*, until having passed *q.*, it arrives at *v.*, the point corresponding to that of *n.* in the neighbouring system. The conditions will be now similar to those preceding, when the comet was at *n.*, and moving towards *A.*, only that the relation of the two centres of gravitating influence to each other in respect to the comet will now be reversed; and the comet will now leave *A.*, and approach *B.*, moving through

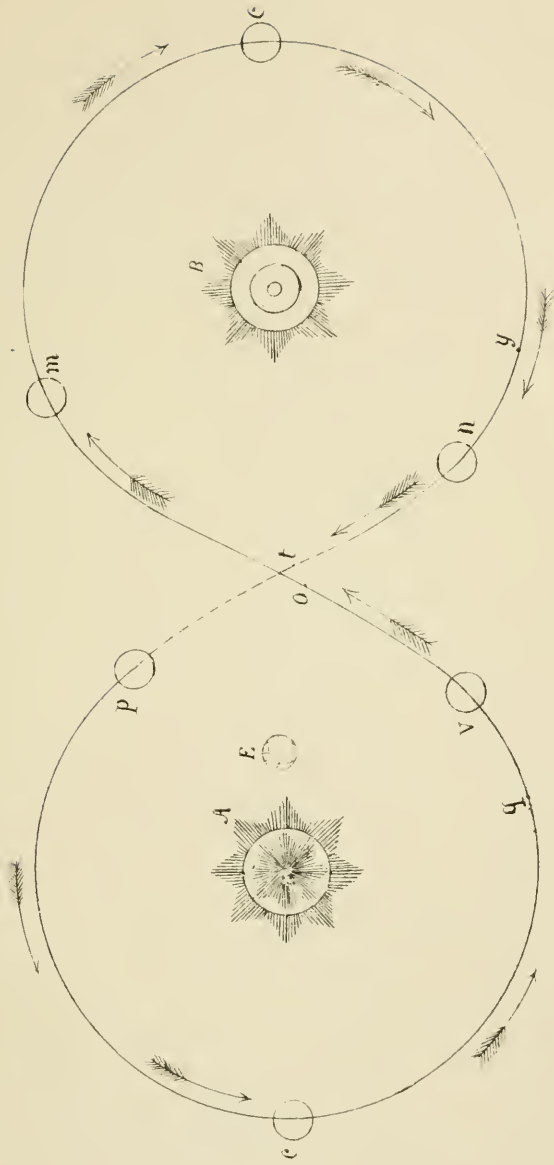
the compound curve *v. t. m.*, which is similar to the curve *n. t. p.*, through which *A.* was approached. From *m.* the comet will again traverse the same compound orbital path; and so on continuously, moving in the direction of the arrows.*

If now we assume that such compound orbital path of a sidereal comet may be in a plane vertical to that of the solar system, or in the same plane, or in a plane oblique at some angle to the plane of the solar system; it will be at once apparent that to a spectator observing the comet from the earth the difficulty of correctly determining the orbital path by observation must be very great. Fig. 2 (Pl. 1) may serve to convey a clearer idea of the difficulty. *E.* represents the earth, and the orbit of the comet is supposed to be vertical to the ecliptic (or to the plane of the sun's equator). If the comet, on entering its solar orbit from *t.* in the direction *t. p.*, became visible from the earth, the orbital motion of the earth would be *apparently* transferred to the comet, which apparent motion, in the reverse direction to the actual motion of the earth, would combine itself with the real motion of the comet; and thus give the appearance to an observer on the earth of an approach to the sun in an oblique direction.

The law of gravitation permits us to suppose that a mass of aggregated matter may thus have its motion con-

* This explanation in respect to the uniformity of the comet's distance from the centre of gravitation is provisional only: it will be seen hereafter that our theory supposes an expanding compound orbit, viz., that the comet on leaving the one orbit and entering the other approaches nearer than its average distance to the centre of gravitation, and then commences and continues to recede (spirally) from that centre, until it (the comet) again enters the former orbit where, in like manner, it approaches that centre and then commences to recede, and so on. See *illustration and remarks*, page 22.

Fig. 2.



trolled and regulated by two distinct centres of gravitating influence ; nor are we prevented from supposing that the orbit may be yet more complex, and that three or even several systems may be traversed in a similar manner and in obedience, as already explained, to the recognized law of gravitation. Fig. 3 (Pl. 2) shows the orbital path of a comet which is supposed to be controlled by three distinct centres of gravitating influence ; the arrows and the explanation already given will sufficiently indicate the manner in which the orbit is compounded.

In either of these cases it is evident that the comet would be periodic ; and if, in any part of its orbit, it approached the earth to within visual distance, the time of its return, after several such visitations had been observed and noted, might be safely predicted.

(2) *The compound solar and planetary orbit.*

It may be objected to the foregoing that there are certain comets which are known as belonging altogether to the solar system, of which the periods are too short to admit the supposition of their travelling beyond the influence of the sun, and of which the orbits and elements have been calculated on the eccentric hypothesis, and the results of the calculations confirmed and verified by actual observation. But a planet, which is secondary to the sun as the general centre of the system, may be, is of sufficiently large size, primary to bodies of much less mass, as for instance the earth to the moon, or either one of the large planets to the satellites which revolve about them as their centre of gravitating influence. Evidently therefore, the law of gravitation allows us to suppose that a planet of large size, which, as a planet, is secondary

to the sun, may also serve together with the sun as one of two primaries controlling the motion and determining the orbital path of a comet: the requisite conditions of the case being that the relative distance of the cometary body from the sun and from the planet is proportional to the relative masses of the sun and the planet. For example, in Fig. 4, (Pl. 3), *J.* represents the planet Jupiter, *S.* the Sun, and *C.* a cometary body: the comet's orbital path is indicated by the arrows. The conditions of this case will be essentially similar to those explained in the example of Fig. 1. In that example the two centres of gravitating influence were supposed equal; and in this, the mass of the sun is much greater than that of Jupiter, but the orbital distance of the body *C.* from the sun is assumed to be also greater than its orbital distance from Jupiter, in the same proportion; and therefore when the body in Fig. 4 arrives at (about) the point *m.* it will be essentially in the same case as at the point *n.*, in Fig. 1, viz.: the attraction of the planet, adding its influence to the centrifugal force, will in the first place cause a deviation towards the tangential direction outside the circular orbit; a little further on, the attractions of the planet and of the sun will be equal, and the body will move in the tangential direction, thereby receding from the sun and approaching the planet; thus when the point *n.* has been reached the more distant and feeble influence of the sun will operate only in diminishing the (increased) velocity, and the cometary body becomes a satellite of the planet throughout *n. a, p.*, about three-fourths of a revolution, until on arriving at (about) the place *p.* the former conditions are reversed, and the comet receding from the planet returns to its solar orbit *q. b. m.* It is

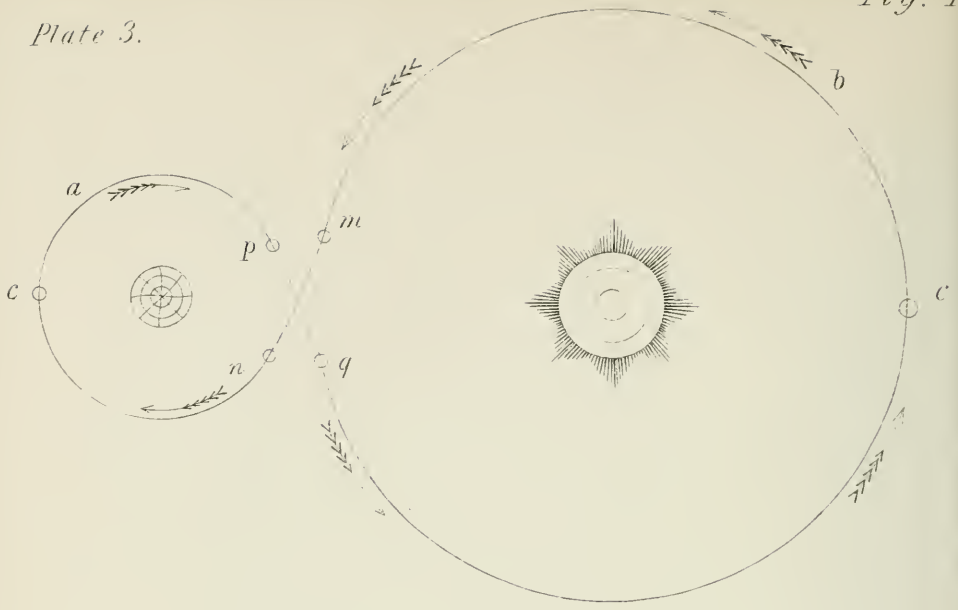
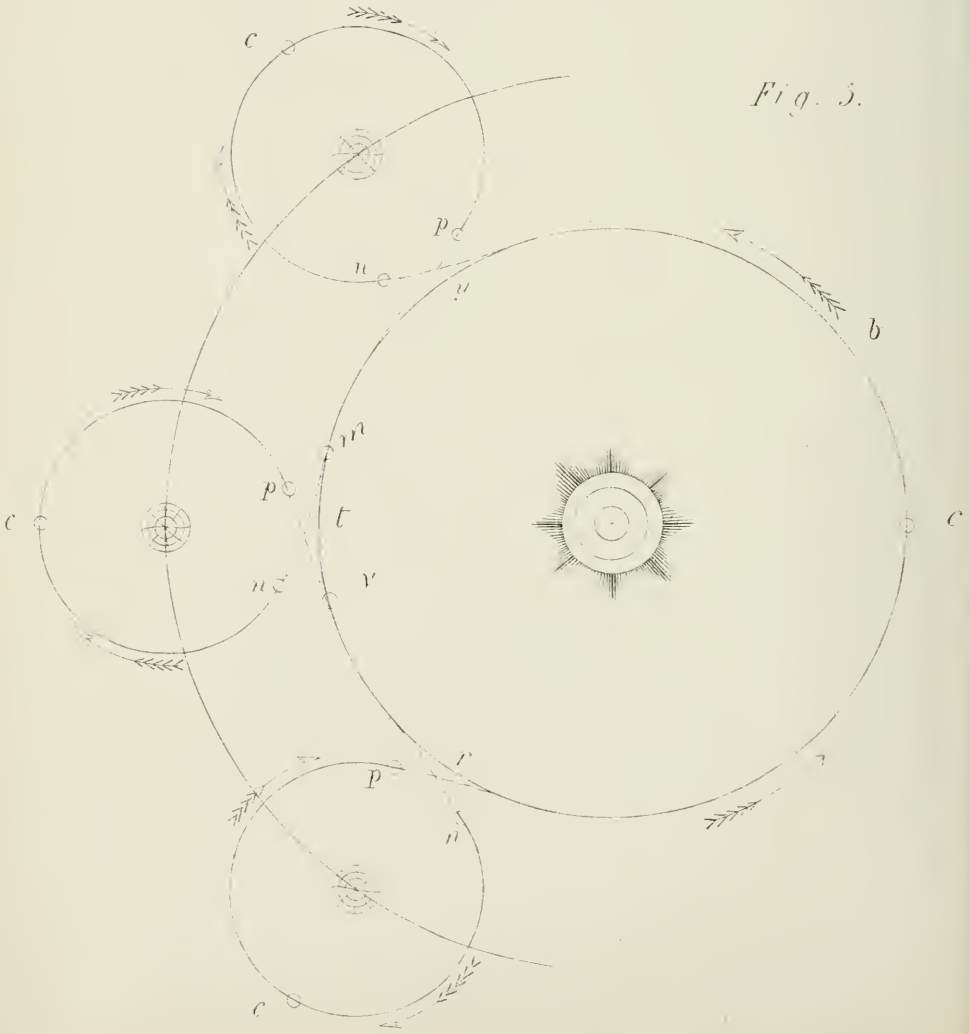


Fig. 5.





true, the planet is itself in motion revolving around the sun; but this will only modify the orbital path of the comet in such wise that...if, on the one hand, the motion of the comet is in the same direction as that of the planet, it will have to overtake the motion of the planet before leaving its solar orbit, which will thus be, in the first place, increased; but, since the distance after leaving the planet and returning, will be so much less, the entire orbit, measuring from a definite (fixed) point will be the same; or on the other hand, if the orbital motion of the comet be supposed in the reverse direction to that of the planet, then the motion of the planet will become, in the first place, a deduction from the solar orbit of the comet; because the planet will then (so to speak) meet the comet, but this will again be compensated by the greater distance which the comet has to travel after leaving the planet. In this last case, where the motions are in the reverse direction to each other, the distance travelled by the comet in one complete compound revolution, proportionally to the orbital distance from the sun, would evidently be greater than in the first case where the motions are in the same direction; because in the first, the planet carries the comet, by so much, onward in the direction of its goal; and in the second case, carries it, an equal distance, back again towards the starting point. This will be readily seen by repeating the figure; thus in Fig. 5, (Pl. 3), we will suppose that, during the time required by *C.* to move from *q.*, through its solar orbit *q. b. m.*, the planet *J.* moves in its orbit from *t.* to *r.*; the comet *C.* will then require to continue in the solar orbit until having passed the point *q.* and having thus more than completed a revolution round the sun, it overtakes the planet and

returns to the planetary orbit at $n.$; or, on the contrary, if we suppose, during the same time, the planet to have moved in the opposite direction from $t.$ to $y.$, the comet, before it arrives at its former place of departure in the solar orbit $m.$, will meet the planet and enter the planetary orbit, as before, at $n.$ *

However, having noticed this difference as theoretically worthy of remark, we will dismiss it as practically inapplicable, because the plan of the solar system does not, as we opine, admit of such reverse motion. We believe that all the celestial bodies under the particular government of the sun, whether called planets or comets, revolve around that central luminary in the same direction without any exception.†

It is known that the earth, which is much nearer to the sun, moves in its orbit with a proportionally greater angular velocity than the planet Jupiter; now, if we were at liberty to assume that the comet moved with a

*It must be remembered, however that the comet in becoming for a time a satellite of the planet, still belongs to the solar system and is still subject to the direct influence of the sun, which is now combined with the more immediate influence of its primary the planet. If the supposition of a possible reverse motion be entertained, the planetary orbit will be to some extent modified by the direction of motion of the comet relatively to that of the planet, because, referring to the figure (Fig. 5), in the one case, the motion of the comet, on entering the orbit, will cause it to approach, and in the other to recede from the planet, thus, in the first instance, increasing or decreasing the angular velocity and in either case resulting in an elliptical orbit.

+ This does not include the case, proposed at page 12 *et seq.*, of a comet owing a divided allegiance to the sun as one of two or more centres of gravitation, and in which case the direction of the motion may be reverse.

considerably greater angular velocity than the earth, it is evident that, if the three bodies were relatively so situated at a particular time, the comet might be visible from the earth before entering the planetary orbit, and during the time of its revolution around the planet, the earth might pass the planet, and soon afterwards the comet returning to its solar orbit, and overtaking the earth might again become visible therefrom; but such would be an assumption which we are not permitted to make, because it would include an assumption that the matter of which the cometary body consists is subject to a law of gravitation differing from that law to which the earth and the other planetary bodies are subject; for if the law be the same, the angular velocity of the comet in its solar orbit, cannot be even so great as that of the earth; for example, let us suppose it equal to that of the earth; then since the radial distance of the comet from the sun is greater than the radial distance of the earth from the sun, the linear velocity of the comet must be greater than that of the earth proportionally to the relative distance; it follows that the radial distance being greater, the gravitating influence of the sun is less on the matter of the comet than on the matter of the earth; but the angular velocity of the comet is (by the supposition) the same as that of the earth, and consequently, the centrifugal force influencing the matter of the comet is greater than that influencing the matter of the earth; therefore under the supposed conditions, the comet would necessarily recede to an orbital path at a greater distance from the sun, whereby, the angular velocity being reduced, the requisite counteracting equality between the gravitating and centrifugal forces would be established. *Part First, p. 44.*

(4) *Terrestrial-and-Solar Comets.*

If we now suppose the earth to take the place of the planet Jupiter in a case similar to that illustrated in Fig. 4 ; the question as to whether or not the comet so approaching and partially revolving around the earth at the distance of a few million miles would be visible from the earth must depend upon the mass (size) of the comet and its luminous or non-luminous character.

Let us here again consider how completely such a theoretical *terrestrial-and-solar* comet would fulfil the observed phenominal conditions frequently witnessed from the earth.

Referring to Fig. 4, (Plate 3), the comet entering the terrestrial orbit from *m.* towards *n.* becomes visible: what is its velocity? Since its radial distance from the sun is not much less than that of the earth, its angular velocity in the solar orbit must be nearly equal to that of the earth. If, therefore, in its terrestrial orbit, its distance from the earth were not greater than that of the moon from the earth, we should have the linear velocity defined as rather less than the linear velocity of the earth compared with the linear velocity of the moon, and which is about 31 times greater. In such case the comet would travel through its terrestrial orbit in rather more than one day and then appearing to pass through its perihelion as it crossed the sun, would be again seen as it departed in its solar orbit from *q.* towards *C.*

But if instead of supposing the distance of the comet in its terrestrial orbit to be the same as that of the moon we suppose it to be about 10 times that of the moon, we shall then have the comet, at a distance of two and a half million miles occupying about 12 days in perform-

ing its terrestrial revolution, and then taking its leave of us, until it again, after a long interval, overtakes the earth and repeats its terrestrial circuit. How long would that interval be? Supposing the radial distances from the sun of the orbits to be, respectively, for the comet 90 million, and for the earth $92\frac{1}{2}$ million miles, and the linear velocities to be equal, the angular velocity of the comet would be greater than that of the earth in the proportion of $92\frac{1}{2} : 90$. It would therefore gain two and a half (solar) revolutions in $92\frac{1}{2}$ revolutions, which is equivalent to the gain of one revolution in 37 revolutions. Consequently at the expiration of about 37 years, the comet would again overtake the earth and become visible. It would accordingly be classified as a comet of 37 years period. The compound cometary orbit, as we have (to avoid complexity) illustrated and considered it so far, is subject to certain deviations in respect to the uniformity of its distance from the respective centres of gravitation in different parts of the orbit. Referring again to Fig. 4, and supposing the comet to have almost completed the circuit of the planet and to have arrived at the place *p.*, we have to consider that in consequence of the great angular velocity in its terrestrial orbit, the path of the comet must be in the curve of a spiral expanding outwards from its centre of gravitation—the planet. Consequently the comet is in such wise already receding from the planet; but now, to the effect of the centrifugal force is added that of the sun's direct attraction, and the result is a path not through the point *q.* and in the arc of the circle *q. C.* but considerably nearer to the sun than *q.* and in the arc of a circle (ellipse) having a considerably lesser radial distance

from the sun than q . C . But now, again, the comet is travelling in an orbit wherein the intensity of gravitation and the centrifugal force are not in equilibrium, because the angular velocity of its revolution must have become greater than that belonging to its average distance, proportionally to the distance by which it has approached the sun. Hence, the comet is now moving in the curve of a helix (ellipse)* expanding outwards; when, therefore, the comet arrives at b' . it has receded to a greater distance from the sun than when at C ., and, again, when it arrives in the neighbourhood of m . it is still more distant from the sun. The result of this modifying influence is indicated in Fig. 6, as the compound expanding orbit, whereby, if we suppose the planet to be the earth, we become still better able than before to appreciate the almost sudden manner in which a comet observed by aid of the telescope at a great distance, appears to rush into comparative proximity to the earth, and then commences to recede very gradually at first, as the terrestrial orbit expands its curvature, and after a time (of 10, 20 or 30 days, perhaps,) very rapidly, as the sun adding its power to the centrifugal force overcomes the terrestrial gravitation, and thus, finally, the comet appears to recede with a suddenness and velocity similar to that of its approach.

NOTE.—*Fig. 8 is a repetition on a larger scale of Fig. 6; and Fig. 7 exhibits the similar correction applied to Fig. 5, viz: the compound expanding orbit of a sidereal comet.*

* The fractional curve or arc of a helix may be considered identical with the corresponding curve or arc of an ellipse; but in one, the expansion continues in each succeeding arc; whereas, in the other, centrifugal expansion having reached a certain limit, is succeeded by a corresponding centrepetal contraction, so that the figure becomes finite and complete.

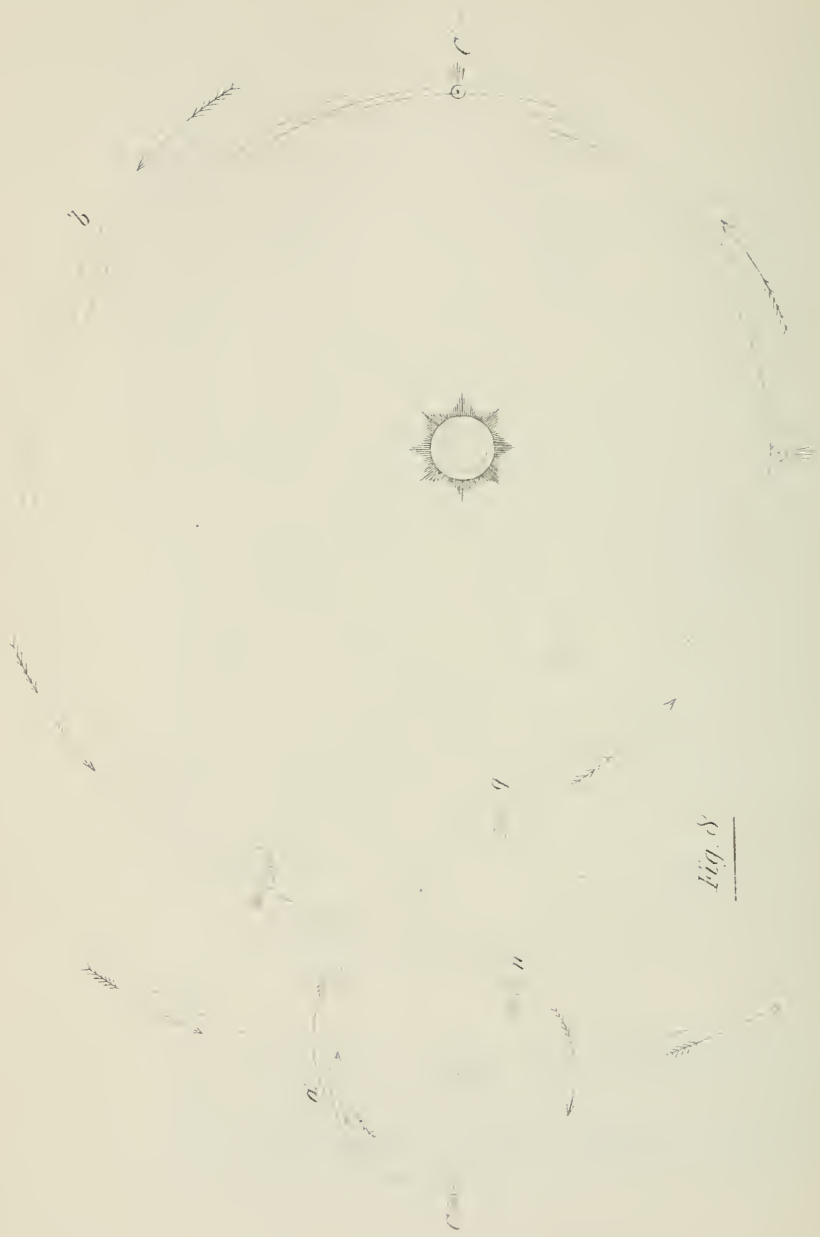


Fig. 8

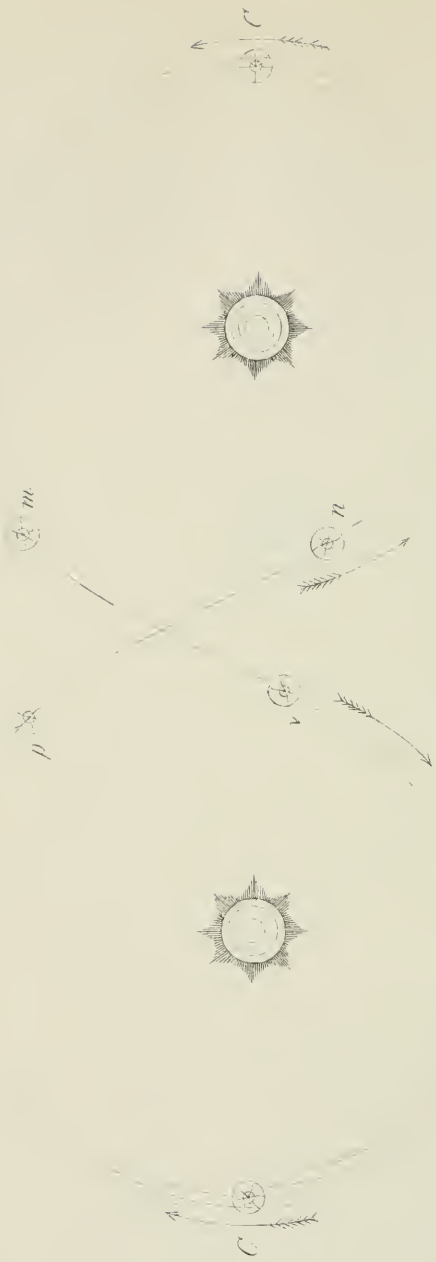


Fig 7

The Compound expanding orbit of
a Sidereal Comet.

CHAPTER II.

THE COMETARY PHENOMENA.

(1) *Theoretical consideration of the phenomena.*

The peculiar appearance of the *coma*, and the luminous characteristic of the train or tail of many of the comets, are appearances of which no satisfactory explanation has been given. With respect to the first, we think that a careful consideration of the evidence which geology furnishes, as to what was certainly the condition of the earth at a time antecedent to the existence of animal and vegetable life thereon, will enable us to understand the nebulous appearance of the *coma* and the comparatively small size and solid appearance of the *nucleus*. Geological theories explaining the primary condition of the earth, appear to be at present in a somewhat incomplete and crude state, contravening more or less the known physical laws of matter. The explanation now perhaps most generally accepted is to the effect that the entire mass, including all the varieties of matter compounding the earth as it now exists, was originally in a state of vapor. This entirely vaporous condition of the earth is supposed to have been succeeded by a liquid nucleus occupying the central part of the vaporous sphere and consisting of the denser varieties of matter in a molten state; after a time, loss of heat having been caused by radiation, a crust is supposed to have been formed on the surface of the liquid (fluid) nucleus, which, being subsequently acted upon by volcanic agency and earthquakes, acquired stability as the cooling

process went on, and eventually became fitted for water to remain on its surface, and for the support of vegetable and animal existence. Now this hypothetical explanation in the first place takes for granted that all those varieties of matter, whether compound or elementary substances, which are now known to us in the solid state may be volatilized by the influence of heat. The evidence of chemistry, in the present state of the science, does not certainly do more than allow of such a supposition as a possibility ; it would be at least as reasonable, on chemical grounds, to suppose that many of these varieties of matter now recognized by us as elementary are not *in fact* elementary, and would be decomposed and separated into their elements if exposed to the exceedingly high temperature contemplated ; and it might be assumed with a greater measure of probability, that even the intense heat supposed would be unable to vaporise (volatilize) or even to liquefy some of those substances now known to us as solids, but that some of them would resist liquefaction even at the highest temperature. But allowing, for a moment, the possibility that intense heat, under favourable conditions, might liquefy and volatilize all the solid forms of matter, yet we find the hypothesis tacitly assuming that the entire mass or quantity of matter compounding the earth has not undergone augmentation ; but that, whether in its present partially liquid and partially solid and gaseous condition ; or, as formerly, in a partially or wholly vaporous state, the aggregate quantity of matter has remained the same. It therefore follows that the (vaporous) centre—that is, the matter (in a vaporous condition) occupying the centre, must have been under the same pressure from the gravitation of the

superincumbent matter as that to which in the same situation it is now subjected. This consideration at once much increases the difficulty of imagining many of those substances, at present only known to us as solids, in a fluid or vaporous state; because we are called on to suppose them able to assume and retain that condition under enormous pressure. It seems much more reasonable to suppose that at the very elevated temperature of the hypothesis the conditions would be . . . the centre of the earth composed of matter in the liquid (fluid) state; exterior to or upon this, a crust of solid matter: then a stratum of dense vapor, becoming more gaseous and attenuated as the distance from the centre increased. On this supposition, as the cooling process gradually advanced, chemical combination and reaction of the materials upon each other would take place within, upon, and above the crust, and, also, the potent agency of volcanic action would be at work from the first in supplying and modifying the constituents, and in fashioning the form of the crust for the ulterior purpose it was intended to serve. We think that a careful consideration of the evidence now afforded by geology, together with the teaching of chemical and physical (meteorological) science, will be found to substantiate this supposition as to the primary condition of the earth. If then we assume that the earth at some former period was in a physical condition substantially such as we have just described, there can be no difficulty in supposing that some masses of aggregated matter, *i. e.*, planetary or cometary bodies, may be at the present time in a similar condition; indeed, it at once suggests itself as a probability that some of those very numerous bodies, of which astronomical observation has

made known to us the existence, are now in such a primary or igneous condition.* Keeping this probability in mind, let us now examine the appearances presented to a terrestrial observer by a comet.

Herschel's Outlines of Astronomy.

(556) "Comets consist for the most part of a large, and more or less splendid, but ill-defined, nebulous mass of light called the head, which is usually much brighter towards its centre, and offers the appearance of a vivid nucleus, like a star or planet. From the head and in a direction *opposite to that in which the sun is situated* from the comet appear to diverge two streams of light, which grow broader and more diffused at a distance from the head, and which most commonly close in and unite at a little distance behind it, but sometimes continue distinct for a great part of their course; producing an effect like that of the trains left by some bright meteors, or like the diverging fire of a sky-rocket (only without sparkle or perceptible motion). This is the tail."

(557) "The tail is, however, by no means an invariable appendage of comets, many of the brightest have been observed to have short and feeble tails, and a few great comets have been entirely without them. Those of 1585, and 1763, offered no vestige of a tail; and Cassini describes the comets of 1665, and 1682, as being as round and as well defined as Jupiter. On the other hand instances are not wanting of comets furnished with many

* If the condition of all the planetary bodies known to us was found to be, so far as we could observe, precisely similar and uniform, the probability would be against the above supposition; but since, on the contrary, observation has made certainly known to us that the present conditions of the various planets are dissimilar and differ very considerably, the probability is strongly in favor of the supposition.

tails or streams of diverging light. That of 1744 had no less than six, spread out like an immense fan, extending to a distance of nearly 30° in length. The small comet of 1823 had two, making an angle of about 160° , the brighter turned as usual from the sun, the fainter towards it, or nearly so. The tails of comets, too, are often somewhat curved, bending, in general, towards the region which the comet has left, as if moving somewhat more slowly, or as if resisted in their course."

Lardner's Astronomy.

(3092) "The comet (Halley's comet 1835) first became visible as a small round nebula, without a tail, and having a bright point more intensely luminous than the rest eccentrically placed within it."

Also, see Illustrations, Plates 9, 10, 11, 12, 13.

(2) *Explanation of the Phenomena.*

The description given by others of the general appearance of comets, is in agreement with the foregoing, viz., as consisting of a nebulous mass, more or less luminous, at or near the centre of which is the nucleus having the appearance of concentration or solidity, and which is also more vividly luminous; the tail or train of luminous matter which forms part of the usual cometary appearance, varying greatly in form and extent.

Now if we suppose a planetary mass of matter in a condition similar to that of the earth in its primary state, moving at a very considerable distance from the earth, the appearance it might be expected to present, leaving out of consideration for the moment the luminous train or tail, would be precisely that described as belonging to the comet; viz., the spherical mass of matter in a liquid (molten or fluid state) occupying the central part of the

body, covered by the solid crust in an intensely heated condition and surrounded by the vaporous and gaseous envelope, would give the appearance of the nucleus and the coma. The supposition that the peculiar general appearance of cometary bodies is correctly accounted for in this manner is strengthened by astronomical observation which teaches us that all comets do not present this peculiar appearance but are sometimes more similar and sometimes more dissimilar to ordinary planets. Thus “Cassini describes the comets of 1665 and 1682 as being as round and well defined as Jupiter; “the comets of 1585 and 1763 offered no vestige of a tail;” and “the smaller comets, such as are visible only in telescopes or with difficulty by the naked eye, and which are by far the most numerous, offer very frequently no appearance of a tail, and appear only as round or somewhat oval vaporous masses, more dense towards the centre, where, however, they appear to have no distinct nucleus, or anything which seems entitled to be considered as a solid body.” (Herschel’s Outlines.)

(3) *Natural division of comets into two classes.*

From the explanation which has been now given as to the orbital paths of comets, it follows that the observed comets would divide themselves into two classes,* viz.

*A third class would be those comets (if we suppose there are any) which belong entirely to some other system, and become occasionally visible from the earth; there is a probability that those comets of long period which have their orbital plane vertical or nearly vertical to the ecliptic, will be found to belong to this third class; and still more so where the motion is in the reverse direction to that of the planets belonging to the solar system. Again, the planetary comets might be divided into terrestrial and planetary comets; the first group containing all the comets of which the earth is the secondary centre of gravitation, and the second, all those having one of the other planets, to wit: Venus, Mars, Jupiter, Saturn, as the secondary centre.

sidereal (and solar) and planetary (and solar) comets; the former only partially, and the latter wholly belonging to the solar system. The former would evidently have orbital distances from the sun of great magnitude compared to the latter; and, in cases where the periodical return is observable, the periods of those belonging to the first class would be proportionately greater than those of the second. In comparing this reference with the record of actual observation, we find: "Here also we may notice a very curious remark of Mr. Hind (Ast. Nach. No. 724) respecting periodic comets, viz., that so far as at present known, they divide themselves for the most part into two families, the one having periods of about 75 years, corresponding to a mean distance about that of Uranus; the other corresponding more nearly with those of the asteroids, and with a mean distance between those small planets and Jupiter. The former group consists of four members; Halley's comet revolving in 76 years, one discovered by Oblers in 74, De Vico's 4th comet in 73, and Brorsen's 3rd in 75, respectively. Examples of the latter group are to be seen in the tables at the end of this volume." (*Herschel's Outlines*.) "We may add, too, a marked tendency in the major axis of periodical comets to ground themselves about a certain determinate direction in space, that is to say, a line pointing to the sphere of the fixed stars northward to 70° long. and 30° N. lat. or nearly towards the star λ Persei (in the Milky Way), and in the southern to a point (also in the Milky Way) diametrically opposite." (Ast. Nach. No. 853.)

(4) *The prevalent Theory of Cometary Orbits, and the facts of Astronomy*

Persons who, it may be, are only slightly acquainted with astronomy, in a scientific sense, are likely to somewhat misunderstand the nature of the connection between the prevalent astronomical theory as to the cometary revolutions, and the astronomically observed facts belonging to the same subject. They are informed, or may so understand the matter, that the orbit of a comet having been calculated according to a theory affirming its path to be in an ellipse of extreme eccentricity, and the periodic return of the comet having been found to agree or very nearly so with a prediction based on the result of that calculation, that such argument constitutes a strong probability as to the correctness of the theory, and since, in a number of instances, the predicted return of the comets, of which the orbits have been so calculated, has been verified by the actual return in agreement with the prediction, that the theory is demonstrated by the observed facts, and therefore it is safe to conclude that the eccentric theory of the cometary orbit is established. Such a conclusion is indeed very far from safe. It is true that certain computations based upon the theory are shown to bring out results which are in agreement with certain observed facts, but the nature of the case, which is of a compound character, makes it necessary to examine very carefully whether all the elements of the computation are in agreement with all the elements of the case, or, in other words, with all the known circumstances belonging to the fact, because, computations in which the elements vary greatly, comparing those of the one respectively with those of the other, may bring out

the same general result, and in this particular case the inference is that, as the result of the computation agrees with a certain fact (of observation), therefore all the elements of the computation are necessarily true, or according to fact, also. To point the objection to such an inference, we will observe that any compound arithmetical number may be arrived at, as a result, by combinations, in two or more computations, of elements which respectively (or taken separately) may differ considerably in the one computation from those in the other, for example, take the number 72, which results from $3 \times 6 \times 4$, and also from $3 \times 8 \times 3$, in one of which the 6 and the 4 differ respectively from the 8 and the 3 in the other: and, that the reader may correctly appreciate the merits of the case, we will suppose that the question is not as to whether the result is, or will be 72, because *that* is known beforehand, but as to the particular elements by which the result is produced. With respect, therefore, to the cometary predictions, they seem to amount to, but little more than this; a comet having been visible at a certain date and its appearance noted, and a definite number of years thereafter a comet, closely resembling the first, and apparently the same, having appeared; and again after the same definite number of years, the comet having reappeared; a strong probability suggests itself that the reappearances will be periodic at such intervals, and the next appearance or return of the comet is predicted accordingly. It appears that certain computations based upon a particular theory (the eccentric orbit theory) have been made to harmonize with the intervals of absence and re-appearance of the comets, but there is no sufficient evidence at present, so far as we are aware, of

a relation between the computations and the actual periods of the comets of such a kind as to justify the inference that the theory is supported, or in any way strengthened, by the return of certain comets at definite times, predicted in the manner just stated. Figures 7 and 8 will serve to illustrate the practical application of this argument.

(5) *Biela's Comet.*

Fig. 7, Pl. 5, is taken from *Arago's scientific notices of comets*, and shows the theoretical orbit of Biela's comet, with the supposed relative position of the orbital path of the earth. This comet was seen in 1826, 1832, and 1846; and it is also supposed to have been seen in 1772 and 1805, etc. Its orbit, according to Biela, is a very eccentric ellipse described about the sun in 2410 days, or about $6\frac{3}{4}$ years.

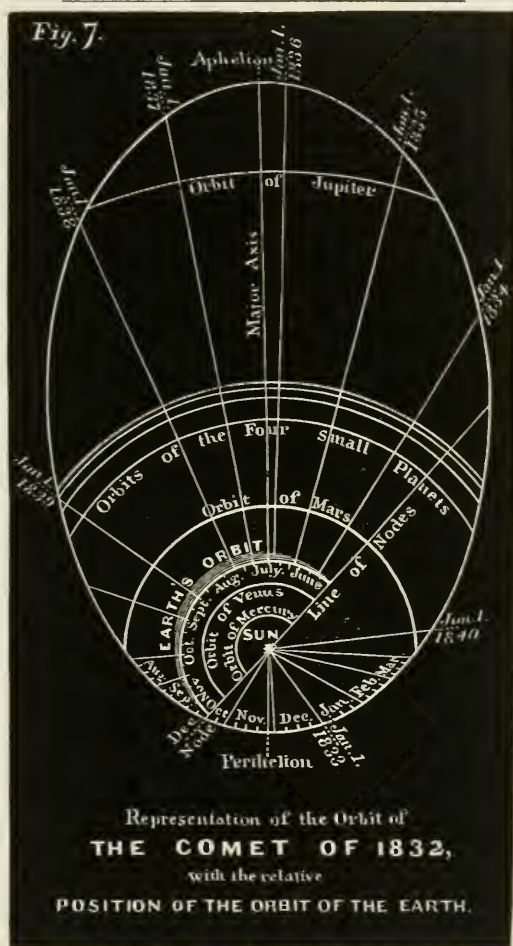
The following quotation from *Lardner's Astronomy* is noteworthy as indirectly illustrating the preceding argument and the succeeding application thereof:

“3024. *Corrected Estimate of the Mass of Mercury*.—The masses of comets in general are, as will be explained, incomparably smaller than those of the smallest of the planets; so much so, indeed, as to bear no appreciable ratio to them. A consequence of this is, that while the effects of their attraction upon the planets are altogether insensible, the disturbing effects of the masses of the planets upon them are considerable. These disturbances, being proportional to the disturbing masses, may then be used as measures of the latter, just as the movement of the pith-ball in the balance of torsion supplies a measure of the physical forces to which that instrument is applied.

Encke's comet near its perihelion passes near the orbit of Mercury, and when that planet at the epoch of its perihelion happens to be near the same point, a considerable and measurable disturbance is

From Dick's Sideral Heavens.

PLATE 5. FIG. 7.



manifested in the comet's motion, which being observed supplies a measure of the planet's mass.

This combination of the motions of the planet and comet took place under very favourable circumstances, on the occasion of the perihelion passage of the comet in 1838, the result of which, according to the calculations of Professor Encke, was the discovery of an error of large amount in the previous estimates of the mass of the planet. After making every allowance for other planetary attractions, and for the effects of the resisting medium, the existence of which it appears necessary to admit, it was inferred that the mass assigned to Mercury by Laplace was too great in the proportion of 12 to 7.

This question is still under examination, and every succeeding perihelion passage of the comet will increase the data by which its more exact solution may be accomplished.

3025. *Biela's Comet*.—On February 28th, 1826, M. Biela, an Austrian officer, observed in Bohemia a comet, which was seen at Marseilles at about the same time by M. Gambart. The path which it pursued, was observed to be similar to that of comets which had appeared in 1772 and 1806. Finally, it was found that this body moved round the sun in an oval orbit, and that the time of its revolution was about 6 years and 8 months. It has since returned at its predicted times, and has been adopted as a member of our system, under the name of Biela's comet.

Biela's comet moves in an orbit whose plane is inclined at a small angle to those of the planets. It is but slightly oval, the length being to the breadth in the proportion of about four to three. When nearest to the sun, its distance is a little less than that of the earth. and when most remote from the sun, its distance somewhat exceeds that of Jupiter.* Thus it ranges through the solar system, between the orbits of Jupiter and the Earth.

This comet had been observed in 1772 and in 1806; but in the elliptic form of its orbit, and consequently its periodicity was not discovered. Its return to perihelion was predicted and observed in 1832, in 1846, and in 1852; but that which took place in 1838 escaped observation, owing to its unfavourable position and extreme faintness."

* The distance of Jupiter to that of the earth is, in round numbers, about 5 : 1, therefore the above orbit should be . . . the length to the breadth in the proportion of about $6 : 3\frac{1}{2}$, instead of 4 : 3.

Fig. 8, Pl. 6, exhibits a theoretical orbit of the same comet which we propose to substitute for that of Biela, on the ground that the orbit now proposed affords a reasonable explanation of the observed facts, and which the former (Biela's) does not. The object of contrasting these two figures is, in the first place, to show that the situations in which the comet was actually seen at the various times of the observations, as well as the definite periods of its absence and of its return, *i.e.*, from the time when it becomes invisible until the time when it again becomes visible, can be explained by attributing to the comet an orbit essentially different from that of Biela. We divide the so-called period of the comet, 2410 days by three, and we consider the resulting number, $803\frac{1}{3}$ days, to be (about) the actual period of the comet, that is to say, from the time of an observed appearance until the next. The orbit, as shown by the figure, is compound, belonging in part to the planet Jupiter. It is evident that if we assume these relative periods for the comet and the earth, that the earth will make two complete revolutions and be in advance of the comet by about $73\frac{1}{3}$ days in the 1st period; in the 2nd period, the earth will make two complete revolutions and gain another $73\frac{1}{3}$ days, making together $146\frac{2}{3}$ days, and at the end of the third period, the earth will have made six annual revolutions and have gained 220 days. At this time the comet again becomes visible from the earth in a situation nearly the same relatively to the earth as when it was observed 2410 days previously. During this longer term the comet might be twice visible from the earth; but the frequency of the comet's re-appearance would be, in the first place, dependant upon the relative situation in its orbit of the planet Jupiter, because if the comet was in its planetary

Fig 5.

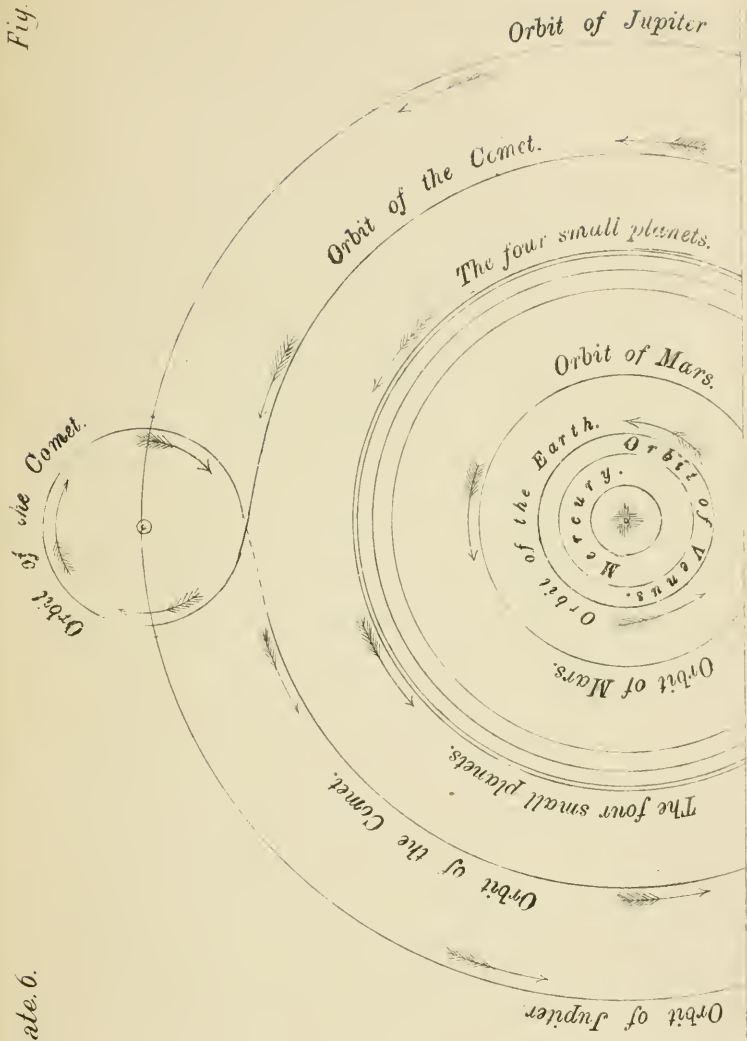


Plate. 6.

The orbit of Biela's comet; assuming it to be a Jovian and Solar comet. Period, 900 days.

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orbit (revolving around Jupiter) at the time that the earth passed by, the comet would not be visible from the earth until overtaken again in the next revolution; and, in the second place, it should be observed that, when the comet becomes visible in November or February, the earth is situated (vertically) much below the plane of the ecliptic, not very far from its point of maximum depression; now, if the comet was seen at that time of the year when the earth is near its point of maximum elevation and therefore much above the plane of the ecliptic, the difference in the apparent relative situation might alone prevent the recognition of the comet. *

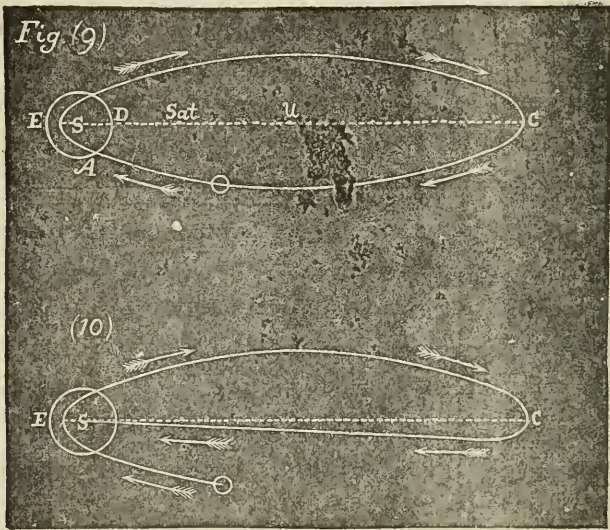
According to this explanation the comet's true period considered as its third return to the same sidereal (or fixed) place in the heavens (*i.e.*, to a place situated at the same point of the solar compass) will be somewhat (about 145 days) more than 7 years, because when the comet again becomes visible the earth requires 145 days to reach its former situation, which would complete the 7 years, and the comet moves with only about one-half the angular velocity of the earth. And, also, since the period of Jupiter is nearly 12 years, that planet would make rather more than half a revolution during the 7 years, so that a great number of these septennial re-appearances might occur before the planet's situation in the zodiac would cause the comet to leave the solar orbit at that particular time of the year when its return was expected, and so prevent its being seen from the earth at the time of its usual re-appearance.

* And moreover the comet must certainly have its periods of vertical elevation and depression which, instead of coinciding with those of the earth, may be in opposition thereto, and hence considerably increase the apparent difference in the relative situation.)

(6) *Notices from the Record of various comets.*

Halley's Comet.

Fig. 9* represents the supposed orbit of Halley's comet, and is a fair illustration of the elliptical orbit of extreme eccentricity, which is now attributed to cometary bodies. We observe that the comet, having nearly reached its perihelion, makes about one-third of a revolution around



the sun in moving from *A* to *B*, but having arrived at *B*, and still being comparatively very near to the sun, it no longer obeys the restraining power of the sun's gravitating influence, but recedes in an almost direct line to a great distance, then, describing a slight curve towards the major axis of the ellipse, it gradually approaches its (supposed) aphelion *C*. Notwithstanding that the comet when at *B*, comparatively close to the sun, was unaffected

* From Dick's "Sidereal Heavens."

by the enormous gravitating force to which it must have been at that place subjected, now, when near *C* at the very great distance *S. C*, it becomes suddenly and sensitively attentive to the comparatively very feeble influence of the sun and describes the short curve shown at *C* (the supposed aphelion); but, here again, it appears quite evident that if the velocity of the comet at this place is so small and the sun's influence sufficiently great to cause the comet to make the comparatively sudden curve shown at *C*, the further result will be the motion of the comet in an almost direct line towards the sun as shown in Fig. 10.

The following are *Mr. Dick's* observations having reference to the figure: "The orbit of Halley's comet is four times longer than it is broad, and the orbits of those comets whose periodical revolution exceeds a hundred or a thousand years must be still more elongated and eccentric. The following figure (Fig. 9) represents the orbit of Halley's comet nearly in its exact proportions—*E. C.* represents the length of the ellipse in which it performs its revolution; *E. D.* the orbit of the earth somewhat longer than it ought to be in proportion to the comet's orbit; *S.* the sun in one of the foci of the ellipse; *Sat.* the proportional distance of the planet Saturn from the sun; and *U.* the proportional distance of Uranus. The orbit of this comet extends to nearly double the distance of Uranus, and considerably beyond the orbit of the lately discovered planet Neptune."

The following extract from *Dr. Lardner's Treatise on Astronomy* will serve to illustrate more especially the subject of the 'planetary comets' by which we mean those which have a compound solar-and-planetary orbit such as we have attributed to the comet known as Biela's.

(3036) “Lexell’s comet.—The history of Astronomy has recorded one singular example of a comet which appeared in the system, made two revolutions round the sun in an elliptic orbit, and then disappeared, never having been seen either before or since.

This comet was discovered by Messier, in June, 1770, in the constellation of Sagittarius between the head and the northern extremity of the bow, and was observed during that month. It disappeared in July, being lost in the sun’s rays. After passing through its perihelion, it reappeared about the 4th of August, and continued to be observed until the first days of October, when it finally disappeared. All the attempts of the astronomers of that day failed to deduce the path of this comet from the observations, until six years later, in 1776, Lexell showed that the observations were explained, not as had been assumed previously, by a parabolic path, but by an ellipse, and one, moreover, without any example at that epoch, which indicated the short period of $5\frac{1}{2}$ years.

It was immediately objected to such a solution that its admission would involve the consequence that the comet, with a period so short, and a magnitude and splendour such as it exhibited in 1770, must have been frequently seen on former returns to perihelion; whereas no record of any such appearance was found.

To this Lexell replied, by showing that the elements of its orbit, derived from the observations made in 1770, were such, that at its previous aphelion, in 1767, the comet must have passed within a distance of the planet Jupiter fifty-eight times less than its distance from the sun; and that consequently it must then have sustained an attraction from the great mass of that planet more than

three times more energetic than that of the sun; that consequently it was thrown out of the orbit in which it actually moved in 1770; that its orbit previously to 1767 was, according to all probability, a parabola; and, in fine, that consequently moving in an elliptic orbit from 1767 to 1770, and having the periodicity consequent on such motion, it nevertheless moved only for the first time in its new orbit, and had never come within the sphere of the Sun's attraction before this epoch. Lexell further stated, that since the comet passed through its aphelion which nearly intersected Jupiter's orbit at intervals of $5\frac{1}{2}$ years, and it encountered the planet near that point in 1767, the period of the planet being somewhat above 11 years, the planet after a single revolution and the comet after two revolutions must necessarily again encounter each other in 1779; and, that since the orbit was such that the comet must in 1779 pass at a distance from Jupiter 500 times less than its distance from the sun, it must suffer from that planet an action 250 times greater than the sun's attraction, and that therefore it would in all probability be again thrown into a parabolic or hyperbolic path; and, if so, that it would depart for ever from our system to visit other spheres of attraction. Lexell, therefore, anticipated the final disappearance of the comet, which actually took place.

In the interval between 1770 and 1779, the comet returned once to perihelion; but its position was such that it was above the horizon only during the day, and could not in the actual state of science be observed."

(3037) "At this epoch analytical science had not yet supplied a definite solution of the problem of cometary disturbances. At a later period the question was assumed

“ by Laplace, who in his celebrated work, the *Mécanique Céleste*, gave the general solution of the following problem : ‘ The actual orbit of a comet being given, what was its orbit before, and what will be its orbit after being submitted to any given disturbing action of a planet near which it passes ?’ ”

(3038.) “ Applying this to the particular case of Lexell’s comet, and assuming as data the observations recorded in 1770, Laplace showed that before sustaining the disturbing action of Jupiter in 1767, the comet must have moved in an ellipse, of which the semi-axis major was 13·293, and consequently that its period, instead of being $5\frac{1}{2}$ years, must have been $48\frac{1}{2}$ years ; and that the eccentricity of the orbit was such, that its perihelion distance would be little less than the mean distance of Jupiter, and that consequently it could never have been visible. It followed also, that, after suffering the disturbing action of Jupiter in 1779, the comet passed into an elliptic orbit, whose semi-axis major was 7·3 ; that its period was consequently 29 years, and its eccentricity such that its perihelion distance was more than twice the distance of Mars, and that in such an orbit, it could not become visible.”

(3039.) “ This investigation has recently been revised by M. Le Verrier (See Mem. Acad. des Sciences, 1847, 1848,) who has shown that the observations of 1770 were not sufficiently definite and accurate to justify conclusions so absolute. He has shown that the orbit of 1770 is subject to an uncertainty, compassed between certain definite limits ; that tracing the consequences of this to the positions of the comet in 1767 and 1779, these positions are subject to still wider limits of uncertainty. Thus he

“ shows that compatible with the observations of 1770, the comet might in 1779 pass either considerably outside or considerable inside Jupiter's orbit, or might, as it was supposed to have done, have passed actually within the orbit of his Satellites. He deduces, in fine, the following general conclusions:

1. That if the comet had passed within the orbits of the Satellites, it must have fallen down upon the planet and coalesced with it; an incident which he thinks improbable, though not absolutely impossible.

2. The action of Jupiter may have thrown the comet into a parabolic or hyperbolic orbit, in which case it must have departed from our system altogether, never to return except by the consequence of some disturbance produced in another sphere of attraction.

3. It may have been thrown into an elliptic orbit, having a great axis and a long period, and so placed and formed that the comet could never become visible; a supposition within which comes the solution of Laplace.

4. It may have had merely its elliptic elements more or less modified by the action of the planet, without losing its character of short periodicity; a result which M. le Verrier thinks the most probable, and which would render it possible that this comet may still be identified with some one of the many comets of short period which the activity and sagacity of observers are every year discovering.”



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